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THE RELATIONSHIP BETWEEN CANADIAN PRAIRIE DRY AND WET MONTHS AND CIRCULATION ANOMALIES IN THE MID-TROPOSPHERE

by

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and
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ATMOSPHERIC ENVIRONMENT SERVICE

National Hydrology Research Centre
Saskatoon, Saskatchewan

1989

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ABSTRACT

We identify dry and wet months over the Canadian Prairies during the 40-year period 1946-1985 and investigate their relationship with the circulation at the 50 kPa (kilopascal) level. The target area is first subdivided into five zones on the basis of characteristic differences in precipitation climatology, and for each zone in turn, the dates of occurrence of Dry and Wet months are determined. These events are then grouped according to five "seasons" and of these, much of the analysis focuses on the two growing seasons: SPRING defined as April and May and EARLY SUMMER, June and July. Anomaly fields for the Northern Hemisphere are constructed at the 50kPa level by "season" and zone, and for the DRY and WET groupings respectively. For each zone, the two 50kPa anomaly fields DRY vs WET are clearly distinguishable, not only over North America but in many instances, upstream and downstream of the continent. The extent to which these teleconnectivities might be used for prediction of dry or wet months over Prairie regions is discussed. Corresponding charts, constructed for the 100KPA level and for 50-100kPa thickness, are compared with the 50kPa level to assess the baroclinicity characteristic of the two precipitation regimes.

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RÉSUMÉ

Notre étude vise à établir le rapport qui existe entre les mois de temps sec et humide enregistrés dans les Prairies canadiennes pendant une période de 40 ans (de 1946 à 1985) et la circulation atmosphérique observée à 50 kPa. Nous avons divisé le secteur cible en cinq zones distinctes selon les différences constatées au chapitre des précipitations, puis déterminé, pour chacune de ces zones, les dates correspondant aux mois de temps sec et humide. Nous avons classé les données recueillies selon cinq "saisons"; toutefois, nos analyses portent principalement sur les deux saisons favorables à la croissance des végétaux: le PRINTEMPS (avril et mai) et le DÉBUT DE L'ÉTÉ (juin et juillet). Nous avons ensuite constitué des champs de données sur les anomalies observées dans l'hémisphère nord à 50 kPa selon les "saisons", les zones et les mois de temps SEC et HUMIDE. Pour chacune des zones, il est facile de distinguer entre les champs de données portant sur les mois SECS et HUMIDES, non seulement au-dessus de l'Amérique due Nord, mais aussi, dans bien des cas, dans les régions situées en amont et en aval du continent. Dans la présente étude, nous discutons de la possibilité d'utiliser ces données pour prédire les périodes de temps sec ou humide dans les Prairies. Nous comparons les courbes correspondant à un niveau de 100 kPa et à la zone située entre 50 et 100 kPa avec celles établies au niveau 50 kPa en vue d'évaluer les caractéristiques barocliniques des deux régimes de précipitations.

PREFACE

The Hydrometeorological Research Division of the Canadian Climate Centre is studying drought events on the Canadian prairies by applying statistical methodologies and the techniques of climate diagnostics. While droughts can develop during any season their impacts on the prairie economy are most severe when they occur during the growing season. The diagnostic study described in this report examined the linkages between circulation anomalies of the 50 kPa height field and the occurrence of very wet or dry months on the Canadian prairies during spring and early summer.

The Division was fortunate to have the services of Dr. John Knox for this investigation. Dr. Knox is well known as a former manager in the Atmospheric Environment Service and more recently as a scientist applying his extensive knowledge of synoptic meteorology to research into atmospheric circulation patterns over the Northern Hemisphere. Dr. Knox combined his knowledge with the expertise and analytical strengths of the Hydrometeorological Research Division and the data processing capabilities of the Monitoring and Prediction Division of the Canadian Climate Centre to carry out this study.

The results indicate that a relationship exists between the Pacific-North America (PNA) oscillation pattern and wet and dry months in the spring and early summer on the Canadian prairies. In addition, relationships also exist between these precipitation anomalies and other well-known circulation patterns including the North Pacific and North Atlantic Oscillations. The existence of these connections suggest many avenues for further research. A knowledge of the factors which produce the PNA pattern at the latitudes and longitudes which influence the Canadian prairies may form the basis for a drought prediction methodology. Further work on pattern recognition procedures and on anomalous winds may lead to a technique which could be integrated into the monthly forecast procedures currently being used by the Monitoring and Prediction Division. The linkages between dry months, hydrological droughts and periods of heat and water stress for plants also need to be elaborated. The possibility of extending these results to the fall and winter months should also be examined.

The Hydrometeorological Research Division intends to continue this work through in-house studies, and extramural

research initiatives. Anyone wishing to comment on the results presented in this report or interested in collaborating in research on this topic is invited to contact the undersigned.

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1. INTRODUCTION

The identification of the meteorological conditions associated with very wet and very dry seasons on the prairies has obvious implications for long range prediction (one to three months). To date there has been very limited skill in the prediction of significantly anomalous precipitation during such a time frame. Due to the importance of this problem for prairie hydrology and agriculture, it was decided to undertake a study with the objective of identifying the Northern Hemisphere 50kPa (kilopascal) flow patterns which characterize the extremely wet and extremely dry months on the prairies. If the deviations of these flow patterns from a long-term average, (i.e. the anomaly fields) turn out to have characteristic organized structures, then it may be possible to use this knowledge in the prediction of anomalously wet or dry months from the predicted monthly mean 50kPa flow.

During the past forty years, there have been many investigations into the the relationship between time-averaged precipitation anomalies and the contemporaneous circulation anomalies of the troposphere. Stidd (1954) calculated the correlation between the spatial field of monthly mean precipitation over the USA and the corresponding field of 70kPa height for the WINTER months . His Figure 7, p.210, displays well-defined patterns with negative correlation over western North America, and positive correlation over eastern. The patterns are north-south oriented, with the maximum negative correlation axis along the 115W meridian, and the positive along 75W.

Many of the investigations tended to focus more or less exclusively on droughts, e.g. Namias (1982a), and Chang and Wallace (1987) both of whose papers examined Hemispheric circulations during heat waves and droughts in the United States Great Plains.

Since we are interested in the two-sided picture, DRY vs WET, and in the concept of distinguishing between circulations which give rise to anomalous precipitation over relatively small geographical areas (as did Stidd) we shall follow his strategy, using however, composited charts instead of correlation fields. Our precipitation domain will be the Canadian Prairies, hopefully to be subdivided into smaller areas with significantly different precipitation characteristics. Height data will be for the 50kPa, 100kPa and 50kPa-100kPa levels, over a domain including most of the Northern Hemisphere, and of course there will be the advantage of a much longer data base than was possible in 1953. Also, we shall prepare the chart analyses for each season, although in this study we shall focus on the growing

season. These results will be interpreted to some extent in terms of teleconnections and blocking patterns.

In summary, the objectives of this study are to determine:
1) if wet and dry months on the Canadian prairies during the growing seasons are associated with characteristic 50kPa flow pattern anomalies over North America and the flanking oceans,
2) if the occurrence of dry and wet months in different geographical areas is associated with the same or different flow anomalies,
3) if structures in the vertical (100kPa, 50kPa) are characteristic of these anomalous circulations,
4) if teleconnection patterns can be used to predict very dry or wet months over specified prairie zones.

2. TELECONNECTIONS AND BLOCKING

In order to provide a framework for synthesizing the salient features of the anomaly composite charts, we have used the concept of teleconnections, a term used to describe the simultaneous correlation between geopotential height fields over widely separated regions of the hemisphere. In classifying the composite charts of our study we shall relate the structures where appropriate, to characteristic teleconnection modes, using with certain modifications the terminology and sign conventions of Wallace and Gutzler (1981). It should be emphasized however, that their results apply to the WINTER season only, whereas our investigation is for all seasons, with emphasis on SPRING and EARLY SUMMER. For this reason we have made much use of the Namias Atlas (Namias, 1981) in order to do comparisons between our composites and teleconnection modes for the corresponding season.

Figure 1 depicts an idealized schematic of 50kPa anomaly teleconnection modes adapted to the SPRING and EARLY SUMMER seasons. Ideally, the North Pacific Oscillation (NPO) is a dipole in which the negative phase features below normal heights to the north and above normal to the south; a situation usually resulting in stronger than average zonal westerlies in the Pacific Ocean mid-latitudes. The positive phase is the reverse, viz. above normal heights to the north and below normal to the south, a situation often resulting in weaker than average zonal westerlies in the mid-latitudes, and sometimes associated with blocking in the high latitudes. The corresponding oscillation over the Atlantic is called the North Atlantic Oscillation (NAO) and the sign conventions are the same. Because the wavelength of the circulation pattern decreases during the warmer months, we have noted that in some of the composites, particularly for the SUMMER, the NPO and/or the NAO are contracted longitudinally and also their intensity is attenuated. They

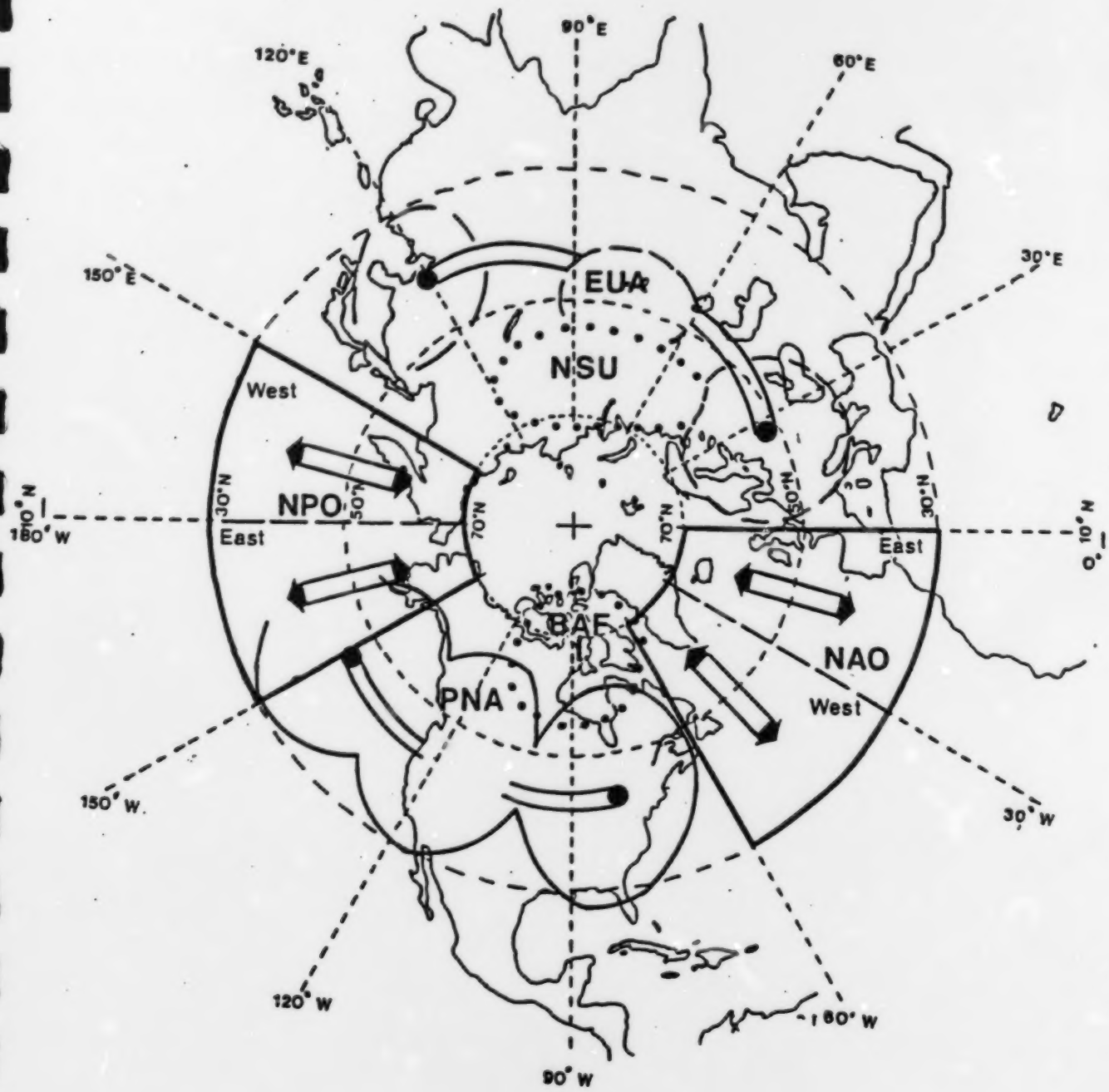


FIGURE 1: Highly idealized representation of characteristic Northern Hemisphere 50kPa height anomaly teleconnection modes adapted to Spring and early Summer. For definitions and phase sign conventions, see text.

may be located in either the western or the eastern halves of the respective oceans, but not necessarily both, and in some SUMMER composites they are simply not discernible at all.

The two other patterns depicted, the Pacific-North America (PNA) and the Eurasian (EUA) have primarily a west-to-east orientation. The PNA pattern, the three lobes of which are usually highly correlated, will be highly germane to our study. On the other hand, the EUA pattern is poorly defined during late spring and summer months and therefore will not be referred to during discussion of our composites for that time of year.

Finally, a word of caution with regard to the use of Figure 1. Our composites are not teleconnection analyses, although, as demonstrated by Stidd (1954), the patterns are relatively similar. Moreover, the atmosphere is a continuum, and therefore rigid adherence to a framework designed for ease of catagorization is carried out at one's peril. Sometimes the areas will have substantial overlap, e.g. the western lobe of the PNA with the eastern sector of the NPO, and the eastern lobe of the PNA with the southwestern sector of the NAO. Notwithstanding the ambiguities which could arise, we decided that the framework of Figure 1 would assist us with the synthesis of the composite analyses.

Blocking events are closely associated with characteristic signatures, which are positive anomalies whose centres meet amplitude and latitude threshold criteria as developed in Knox and Hay (1983). The criteria are also seasonally dependent. In effect these blocking signature events are a subset of the totality of amplified positive and negative anomalies occasioned by the low frequency variation (periods of 10 to 30 days) of 50kPa heights which occurs north of 45N. As already mentioned, the positive phases of the NPO and NAO are often associated with North Pacific and North Atlantic blocking. The spatial distribution by season for the Northern Hemisphere blocking signature frequency will be found in Knox and Hay (1985) to be referred to as K-H. Their analysis discloses that there are two additional areas of significance which fall outside of the teleconnection pattern boundaries of Figure 1. One is the Baffin Island region (including northern Hudson Bay) which is also an area of maximum standard deviation of 50kPa monthly mean heights (Crutcher and Meserve, 1970). The other, designated as Northern Soviet Union (NSU), is also an area of high variability (ibid) and frequent short-term blocking (K-H).

3. SELECTION OF PRAIRIE CLIMATE ZONES AND REPRESENTATIVE STATIONS

We realized that the vast extent of the Canadian Prairies, from the Peace River watershed in the northwest to southeastern Manitoba, a distance of some 1800 kms would make it very unlikely that the area could be treated as a single climatic zone in a sense that would be useful to this study. Indeed this was the implicit conclusion of a study of Canadian Prairie precipitation by Longley (1972). The question was how to subdivide the area into zones with distinguishable precipitation climates. We used the results of a recent paper by Richman and Lamb (1987) which provided a principal component analysis of growing season precipitation patterns in Southern Canada. It should be noted that Richman and Lamb analyzed three and seven day precipitation totals for the growing season months only (May to August). Nevertheless their findings did provide a plausible starting point and by adapting them to those of others (e.g. AES Drought Study Group, 1986) we chose the five zones displayed in Figure 2, and geographically described as follows:

Zone 2. Southeastern Saskatchewan, and southwestern Manitoba, comprising most of the Assiniboine and Souris River Basins.

Zone 4. Southern Alberta extending into southwestern Saskatchewan, approximating the area historically referred to as the Palliser Triangle (Berton, 1970).

Zone 5. North-central Alberta comprising those portions of the Peace, Athabasca, and N. Saskatchewan river basins which lie within the province.

Zone 6. Southeastern Manitoba, and the Lake of the Woods district of Northwestern Ontario.

Zone 7. Central Saskatchewan, more or less centred at Prince Albert.

Within each zone, it was important to select a group of stations whose combined statistics could reasonably be said to define that zone's precipitation climatology. Priority was given to first-order stations with at least 40 years of precipitation data (1946-1985) located in such a way as to provide a representative precipitation climatology of each zone. It was felt that there was sufficient homogeneity in the precipitation climate for the average of the four stations to represent each zone, and those which were chosen are indicated on the map of Figure 2.

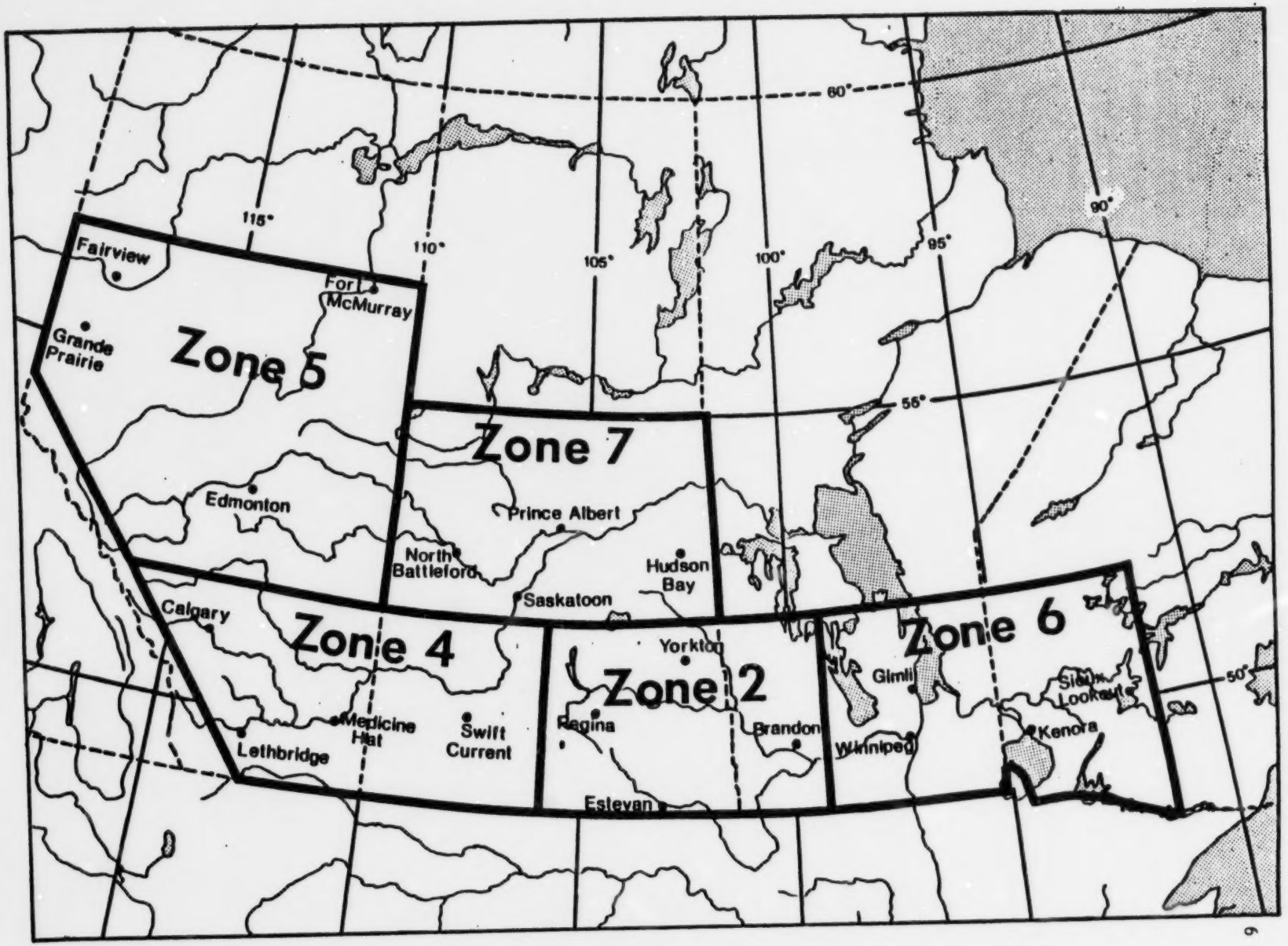


FIGURE 2. The five climate zones and the stations used to define the monthly precipitation.

Figure 3 shows the precipitation by month for the five zones. The graph indicates an annual variation typical of continental climates with precipitation amounts much lower in winter than in summer. In the southern zones (Z6, Z2, Z4) precipitation reaches a maximum during June while the northern zones experience maximum precipitation in July. It is also noted that in Zone 6 precipitation amounts are higher, for each month, than for any of the other zones. In part, this is attributable to the decreasing influence of orography with distance east of the continental divide.

4. DEFINITION OF SEASONS

Although results will be presented for all seasons, the main focus of this study will be on the months of April, May, June, and July, when crops are planted and undergo their maximum growth. We therefore defined a 5-season year as follows:

SPRING	April, May.
EARLY SUMMER	June, July.
LATE SUMMER	August, September.
AUTUMN	October, November.
WINTER	December, January, February, March.

Detailed analyses are presented for SPRING and EARLY SUMMER.

5. DATA SETS

All data are for the period 1946-1985 and normals were calculated using this 40-year span. (It is generally accepted that, prior to 1946, there wasn't sufficient radiosonde data over certain areas of the Northern Hemisphere for reliable circumpolar analyses).

For this period we obtained the record of monthly precipitation at each of the 20 stations (four per zone) displayed in Figure 2.

For the 50kPa level we used a Northern Hemisphere 455 point latitude-longitude grid data set; the origin, shortcomings, and subsequent improvements of which, are detailed in Knox et al (1988). Corresponding data sets for the 100kPa level and the 50-100kPa thickness were also used for the analyses. All of this standard level data was derived from 00Z observations.

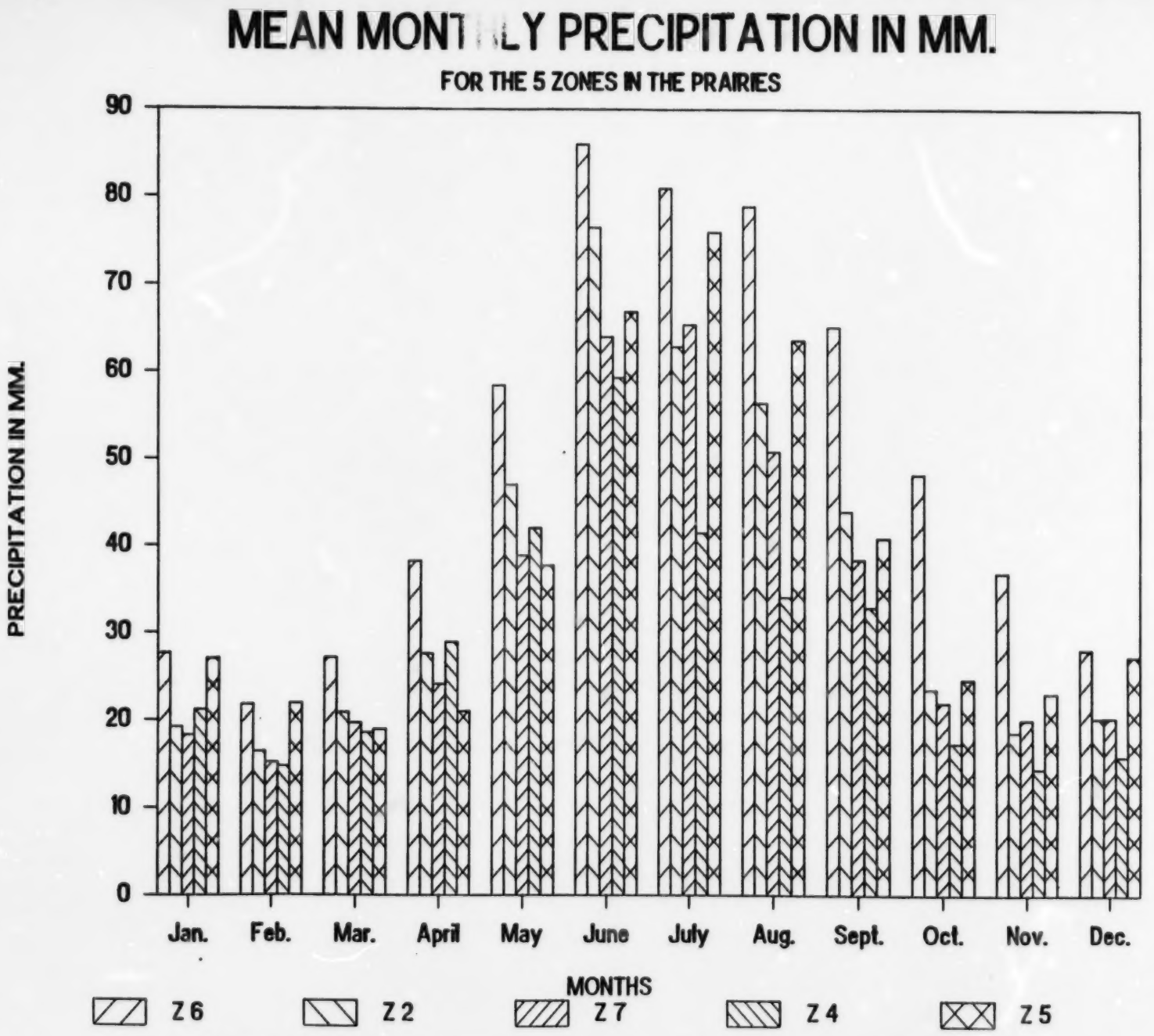


FIGURE 3. Mean monthly precipitation (mms) for the five zones of Figure 2.

6. DEFINITION OF DRY AND WET MONTHS

We reviewed a number of different methods used for defining dry and wet spells, including the Palmer Drought Index (PDI), and the Crop Moisture Index (CMI). Because these indices take into account not only the amount of precipitation, but also factors such as soil moisture, temperature, evaporation and evapotranspiration, they will likely provide better indicators for monitoring drought (and possibly flood) potential than precipitation alone.

However, for the purposes of this study, drought indices were not suitable. One reason is that it was our intention to obtain results applicable to all seasons whereas these indices are not particularly useful from November to March when the ground is frozen. Another reason is that the indices give some weight to antecedent precipitation, whereas our interest was to relate precipitation for the current time frame (say one month) to contemporaneous anomalies in the Northern Hemisphere circulation. Therefore we decided to adopt a purely meteorological definition of a DRY or a WET spell, and used as the basic data unit, the amount of precipitation which occurred during one calendar month.

The dry and wet months for each zone were obtained by computing and ranking the corresponding normalized precipitation anomalies, as described in the following procedure. At a specified station, if Pi was recorded during a given month and PNi equals the normal, then (Pi - PNi)/PNi equals the normalized precipitation anomaly. Four stations were chosen for each zone. Accordingly, the average anomaly for the zone is:

$$\frac{1}{4} \sum_{i=1}^{4} \frac{Pi - PNi}{PNi}$$

For each of the five zones these anomalies were listed by year (1946-1985) and by month, as displayed in the example for Zone 6 in Table 1 . The anomalies were also listed by rank, from maximum to minimum, as illustrated in Table 2, and these provided the basis for selecting the wettest and driest cases.

The selection criteria were as follows:

1. For a WET case, the normalized anomaly must be > 0.5.
2. For a DRY case, " " " " " < -0.5.

To ensure reasonable sample sizes for the map composites, an additional caveat (that was rarely necessary to invoke) was that, in the event that there were fewer than five qualifying cases per month, the next ranking cases became

TABLE 1. Listing by Year and Month of the normalized precipitation anomalies for Zone 6. (See text for details)

AVERAGE OF NORMALIZED ANOMALIES FOR ZONE 6
[GIMLI A (Pi-Pn)/Pn + KENORA A (Pi-Pn)/Pn + SIOUX LOOKOUT (Pi-Pn)/Pn + WINNIPEG (Pi-Pn)/Pn]/4

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1946	-0.267	0.340	-0.019	-0.311	-0.423	-0.317	-0.197	-0.330	0.331	0.336	-0.117	-0.470
1947	0.195	0.340	-0.388	-0.086	-0.273	0.314	-0.390	0.344	-0.200	-0.191	-0.116	0.707
1948	-0.399	-0.167	-0.177	0.054	-0.476	-0.283	0.613	-0.415	-0.773	-0.714	0.023	0.666
1949	0.817	0.418	-0.095	-0.705	-0.384	-0.225	-0.031	-0.153	-0.121	1.727	0.153	0.411
1950	0.712	-0.002	-0.231	0.164	0.670	-0.044	0.018	-0.489	0.244	-0.006	-0.063	0.198
1951	-0.501	-0.213	0.269	-0.120	-0.490	-0.023	-0.424	0.002	0.065	-0.207	-0.435	-0.087
1952	-0.336	-0.197	-0.389	-0.614	-0.664	0.379	0.152	-0.458	-0.595	-0.485	-0.374	-0.494
1953	0.419	-0.121	0.157	-0.218	0.665	0.107	0.752	-0.304	0.151	-0.225	-0.484	-0.297
1954	0.909	0.217	-0.444	0.783	0.175	0.178	-0.446	-0.058	0.515	-0.118	0.291	-0.796
1955	0.387	0.703	0.144	-0.427	-0.083	0.154	-0.265	-0.079	-0.303	0.180	1.624	0.739
1956	0.743	0.262	0.148	-0.461	0.161	-0.205	-0.096	0.326	-0.508	0.039	0.405	0.554
1957	-0.410	0.155	-0.040	0.566	-0.295	0.215	-0.406	-0.278	0.131	-0.323	-0.004	-0.399
1958	-0.320	-0.036	-0.411	-0.160	-0.552	-0.252	0.995	-0.401	-0.344	0.088	1.776	0.615
1959	-0.641	-0.056	-0.231	-0.323	0.973	-0.413	0.333	0.205	0.484	0.630	0.007	-0.192
1960	0.128	-0.183	0.215	0.691	-0.177	-0.204	-0.491	0.593	-0.416	-0.045	-0.163	0.007
1961	-0.535	1.332	-0.325	0.311	-0.617	-0.693	0.112	-0.586	0.119	-0.413	-0.316	0.345
1962	0.085	1.567	0.456	-0.400	0.953	-0.462	0.996	1.315	-0.628	-0.400	0.532	-0.207
1963	-0.584	0.355	-0.446	1.196	0.115	0.266	-0.012	-0.211	-0.707	-0.570	-0.146	0.076
1964	0.424	-0.416	0.688	-0.547	-0.207	0.380	-0.210	0.414	0.269	-0.444	-0.175	0.470
1965	-0.696	0.334	-0.203	0.514	0.511	0.083	0.156	-0.480	0.365	-0.291	0.839	0.409
1966	-0.312	-0.323	0.684	0.432	-0.297	-0.194	0.052	0.071	-0.479	-0.148	0.073	0.264
1967	0.185	-0.489	-0.190	0.618	-0.397	-0.171	0.043	-0.031	-0.776	0.174	-0.352	0.198
1968	0.107	-0.617	0.110	-0.094	0.606	0.206	0.460	0.527	0.007	0.142	-0.761	-0.395
1969	1.472	-0.507	-0.622	-0.630	0.430	0.137	0.136	0.350	0.124	-0.342	-0.405	-0.019
1970	-0.145	-0.226	0.219	0.553	0.550	-0.138	0.331	-0.129	0.649	0.611	-0.136	0.359
1971	-0.595	-0.305	0.410	0.605	-0.247	0.094	0.113	-0.611	0.173	1.181	0.055	-0.468
1972	0.085	-0.331	0.281	-0.707	-0.444	-0.467	-0.211	0.028	0.382	-0.362	-0.348	0.177
1973	-0.833	-0.209	-0.401	-0.217	-0.141	0.252	0.209	0.155	0.955	0.210	0.401	-0.209
1974	0.530	-0.324	0.010	0.924	0.753	-0.330	-0.561	0.857	-0.038	-0.613	-0.513	-0.540
1975	1.091	0.026	-0.025	-0.128	-0.335	0.212	-0.244	0.357	-0.162	-0.033	-0.567	-0.227
1976	0.213	0.147	0.251	0.047	-0.797	0.570	-0.599	-0.466	-0.757	-0.695	-0.740	-0.221
1977	-0.282	0.466	-0.167	-0.740	1.126	0.391	0.196	0.057	1.075	-0.468	0.696	0.029
1978	-0.398	-0.532	-0.102	-0.169	0.625	-0.351	0.267	-0.467	0.101	-0.645	0.221	-0.027
1979	-0.641	0.195	1.124	0.582	0.534	-0.369	-0.270	-0.097	-0.284	0.100	-0.275	-0.016
1980	0.344	0.039	-0.290	-0.885	-0.674	-0.316	-0.324	0.394	0.494	0.034	-0.361	-0.342
1981	-0.428	-0.763	-0.304	-0.458	-0.449	0.411	-0.370	0.071	0.499	0.399	-0.564	-0.437
1982	0.053	-0.320	0.663	-0.368	-0.163	-0.239	0.794	-0.151	0.023	0.482	-0.605	0.095
1983	-0.081	-0.140	0.755	-0.695	-0.377	0.519	-0.330	-0.371	-0.153	-0.124	0.246	-0.408
1984	-0.290	-0.256	-0.449	0.153	-0.210	0.784	-0.358	-0.618	-0.018	1.637	0.030	0.242
1985	-0.205	-0.159	-0.633	0.177	0.327	0.043	-0.494	1.116	0.105	-0.105	0.650	-0.311

TABLE 2. Listing by Rank and Year-Month, of the normalized precipitation anomalies for ZONE 6.

RANKED AVERAGE OF NORMALIZED ANOMALIES FOR ZONE 6
(GIMLI A (Pi-Pn)/Pn + KENORA A (Pi-Pn)/Pn + SIOUX LOOKOUT (Pi-Pn)/Pn + WINNIPEG (Pi-Pn)/Pn)/4

Jan.		Feb.		Mar.		April		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
1969	1.472	1962	1.567	1979	1.124	1963	1.196	1977	1.126	1984	0.784	1962	0.996	1962	1.315	1977	1.075	1949	1.727	1950	1.776	1955	0.739
1975	1.091	1961	1.332	1983	0.755	1974	0.924	1959	0.973	1976	0.570	1958	0.995	1985	1.116	1973	0.955	1984	1.637	1955	1.624	1947	0.707
1954	0.909	1955	0.703	1964	0.688	1956	0.703	1962	0.953	1983	0.519	1982	0.794	1974	0.857	1970	0.649	1971	1.181	1965	0.839	1948	0.666
1949	0.817	1977	0.466	1966	0.686	1960	0.691	1974	0.753	1981	0.411	1953	0.752	1960	0.593	1954	0.515	1959	0.630	1977	0.696	1958	0.615
1956	0.743	1949	0.410	1982	0.663	1967	0.610	1950	0.670	1977	0.391	1948	0.613	1968	0.527	1981	0.499	1970	0.611	1985	0.650	1956	0.554
1950	0.712	1963	0.355	1962	0.456	1971	0.605	1953	0.665	1964	0.380	1968	0.460	1964	0.414	1980	0.494	1982	0.482	1962	0.532	1964	0.470
1974	0.530	1946	0.340	1971	0.410	1979	0.582	1978	0.625	1952	0.379	1959	0.333	1990	0.394	1959	0.484	1981	0.399	1956	0.485	1949	0.411
1964	0.424	1947	0.340	1972	0.281	1957	0.566	1960	0.606	1947	0.314	1970	0.331	1975	0.357	1972	0.382	1946	0.336	1973	0.401	1965	0.409
1953	0.419	1965	0.334	1951	0.269	1970	0.553	1970	0.550	1963	0.266	1978	0.267	1969	0.350	1965	0.365	1973	0.210	1950	0.291	1970	0.359
1955	0.387	1956	0.262	1976	0.251	1964	0.547	1979	0.534	1973	0.252	1973	0.209	1947	0.344	1946	0.331	1955	0.180	1983	0.246	1961	0.345
1980	0.344	1950	0.217	1970	0.219	1965	0.514	1965	0.511	1957	0.215	1977	0.196	1956	0.326	1964	0.269	1967	0.174	1978	0.221	1966	0.264
1976	0.213	1979	0.195	1960	0.215	1966	0.432	1969	0.430	1975	0.212	1965	0.156	1959	0.205	1950	0.244	1960	0.142	1949	0.153	1984	0.242
1967	0.195	1957	0.155	1953	0.157	1961	0.311	1985	0.327	1968	0.206	1952	0.152	1973	0.155	1971	0.173	1979	0.100	1966	0.073	1967	0.190
1967	0.185	1976	0.147	1956	0.144	1985	0.177	1954	0.175	1950	0.178	1969	0.136	1981	0.071	1953	0.151	1950	0.088	1971	0.055	1950	0.188
1960	0.128	1980	0.039	1955	0.144	1950	0.164	1956	0.161	1955	0.154	1971	0.113	1966	0.071	1957	0.131	1956	0.039	1984	0.030	1972	0.177
1968	0.107	1975	0.026	1960	0.110	1984	0.153	1963	0.115	1969	0.137	1961	0.112	1977	0.057	1969	0.124	1980	0.034	1948	0.023	1982	0.095
1962	0.085	1950	-0.002	1974	0.010	1948	0.054	1955	-0.003	1953	0.107	1966	0.052	1972	0.028	1961	0.119	1950	-0.006	1959	0.007	1963	0.076
1972	0.085	1958	-0.036	1946	-0.019	1976	0.047	1973	-0.141	1971	0.094	1967	0.043	1951	0.002	1985	0.105	1975	-0.033	1957	-0.004	1977	0.029
1982	0.053	1959	-0.056	1975	-0.029	1947	-0.006	1982	-0.163	1965	0.083	1950	0.010	1967	-0.031	1978	0.101	1960	-0.045	1950	-0.063	1960	0.007
1983	-0.001	1953	-0.121	1957	-0.040	1960	-0.094	1960	-0.177	1985	0.043	1963	-0.012	1954	-0.050	1951	0.065	1985	-0.105	1947	-0.116	1979	-0.016
1970	-0.145	1983	-0.140	1949	-0.095	1951	-0.120	1964	-0.207	1951	-0.023	1949	-0.031	1955	-0.079	1982	0.023	1954	-0.118	1946	-0.117	1969	-0.019
1985	-0.205	1985	-0.159	1978	-0.102	1975	-0.128	1984	-0.210	1950	-0.044	1956	-0.096	1979	-0.097	1960	0.007	1983	-0.124	1970	-0.136	1978	-0.027
1946	-0.267	1948	-0.167	1977	-0.167	1950	-0.160	1971	-0.247	1970	-0.130	1946	-0.197	1970	-0.129	1984	-0.018	1966	-0.140	1963	-0.146	1951	-0.087
1977	-0.282	1960	-0.183	1948	-0.177	1970	-0.169	1947	-0.273	1967	-0.171	1964	-0.210	1982	-0.151	1974	-0.038	1947	-0.191	1960	-0.163	1959	-0.192
1984	-0.290	1952	-0.197	1967	-0.190	1973	-0.217	1957	-0.295	1966	-0.194	1972	-0.211	1949	-0.153	1949	-0.121	1951	-0.207	1964	-0.175	1962	-0.207
1966	-0.312	1973	-0.209	1965	-0.203	1953	-0.218	1966	-0.297	1960	-0.204	1975	-0.240	1963	-0.211	1983	-0.153	1953	-0.225	1979	-0.275	1973	-0.209
1958	-0.320	1951	-0.213	1950	-0.231	1946	-0.311	1975	-0.335	1956	-0.205	1955	-0.265	1957	-0.270	1975	-0.162	1965	-0.291	1961	-0.316	1976	-0.221
1952	-0.336	1970	-0.226	1959	-0.231	1959	-0.323	1983	-0.377	1949	-0.225	1979	-0.270	1953	-0.304	1947	-0.280	1957	-0.323	1972	-0.340	1975	-0.227
1978	-0.398	1984	-0.256	1980	-0.290	1982	-0.360	1949	-0.384	1982	-0.239	1980	-0.324	1946	-0.330	1979	-0.284	1969	-0.342	1967	-0.352	1953	-0.297
1948	-0.399	1971	-0.305	1981	-0.304	1962	-0.400	1967	-0.397	1950	-0.252	1983	-0.330	1983	-0.371	1955	-0.303	1972	-0.362	1980	-0.361	1985	-0.311
1957	-0.410	1982	-0.320	1961	-0.325	1955	-0.427	1946	-0.423	1948	-0.283	1984	-0.350	1950	-0.401	1958	-0.344	1962	-0.400	1952	-0.374	1980	-0.342
1981	-0.420	1966	-0.323	1947	-0.388	1981	-0.450	1972	-0.444	1980	-0.316	1951	-0.370	1948	-0.415	1960	-0.416	1961	-0.413	1969	-0.405	1968	-0.395
1951	-0.501	1974	-0.324	1952	-0.389	1956	-0.461	1981	-0.449	1946	-0.317	1947	-0.390	1952	-0.450	1966	-0.479	1964	-0.444	1951	-0.435	1957	-0.399
1961	-0.535	1972	-0.331	1973	-0.401	1952	-0.614	1948	-0.476	1974	-0.330	1957	-0.406	1976	-0.466	1956	-0.508	1977	-0.460	1953	-0.484	1983	-0.408
1963	-0.586	1964	-0.416	1958	-0.411	1969	-0.630	1951	-0.490	1978	-0.351	1951	-0.424	1978	-0.467	1952	-0.595	1952	-0.485	1974	-0.513	1981	-0.437
1971	-0.595	1967	-0.489	1954	-0.444	1983	-0.695	1958	-0.552	1979	-0.369	1954	-0.446	1965	-0.480	1962	-0.628	1963	-0.570	1981	-0.564	1971	-0.460
1979	-0.641	1969	-0.507	1963	-0.446	1949	-0.705	1961	-0.617	1959	-0.413	1960	-0.491	1950	-0.489	1963	-0.707	1974	-0.613	1975	-0.567	1946	-0.470
1959	-0.641	1978	-0.532	1984	-0.449	1972	-0.707	1952	-0.660	1962	-0.462	1985	-0.494	1961	-0.506	1976	-0.757	1978	-0.645	1982	-0.605	1952	-0.494
1965	-0.696	1960	-0.617	1969	-0.622	1977	-0.740	1980	-0.674	1972	-0.467	1974	-0.561	1971	-0.611	1948	-0.773	1976	-0.695	1976	-0.740	1974	-0.560
1973	-0.833	1981	-0.763	1985	-0.633	1980	-0.885	1976	-0.797	1961	-0.693	1976	-0.599	1984	-0.618	1967	-0.776	1948	-0.714	1968	-0.761	1954	-0.796

eligible to make up the five. The absolute value of the anomaly for these latter cases was usually close to 0.5 and never less than 0.35.

For each season lists of qualifying cases were prepared and arrayed by zone, and category (DRY/WET) as shown in Table 3. It turned out that the number of eligible months ranged between ten and twenty per season for WET months and a corresponding number for DRY months. These cases then formed the basis for compositing the 50kPa (and other level) analyses.

7. RESULTS

7.1 Graphical Representation and Interpretation of Composited 50kPa Anomaly Fields

The result of compositing for the case of Zone 2, SPRING, DRY, is illustrated by Figure 4a, and the anomaly field, obtained by subtracting from Figure 4a, the normal 50kPa field for April and May, is displayed in Figure 4b. The corresponding charts for Zone 2, SPRING, WET, are shown in Figures 4c and 4d, respectively. Visually, the difference between Figures 4a and 4c seems small, a result of the zonal component of the hemispheric circulation being from one to two orders of magnitude greater than the meridional. On the other hand, the meridional components, which reflect the nature of the predominant large scale eddy oscillations, are strongly differentiated by the respective anomaly fields, as is apparent from Figures 4b and 4d.

Considering the large spatial variability of monthly precipitation, (compared say, with monthly temperature) and the fact that precipitation amount over a localized region was the sole basis for our map selection criteria, the large scale coherence of, and contrast between, the DRY and WET Anomaly fields exceeded our expectations. What is immediately evident, on comparing Figure 4b (SPRING, DRY) with Figure 4d, (SPRING, WET) is the reversal in E-W polarity over the eastern half of the Pacific Ocean, the USA, the Atlantic Ocean, and western Europe. There is also a reversal in N-S polarity over the Greenland-western Atlantic Ocean sector, an example of opposite phases of the North Atlantic (NAO) Oscillation. Figure 5 which is the result of differencing Figures 4b and 4d shows the location and amplitude of these reversals.

This contrast (between DRY and WET anomaly fields) was found to prevail for the other four seasons and for the other four zones. For example, compare the DRY and WET cases for Zone 6, EARLY SUMMER, as shown in Figures 6a and 6b respectively. Over both the Atlantic and Pacific Oceans there is a reversal of polarity, not only in the east-west

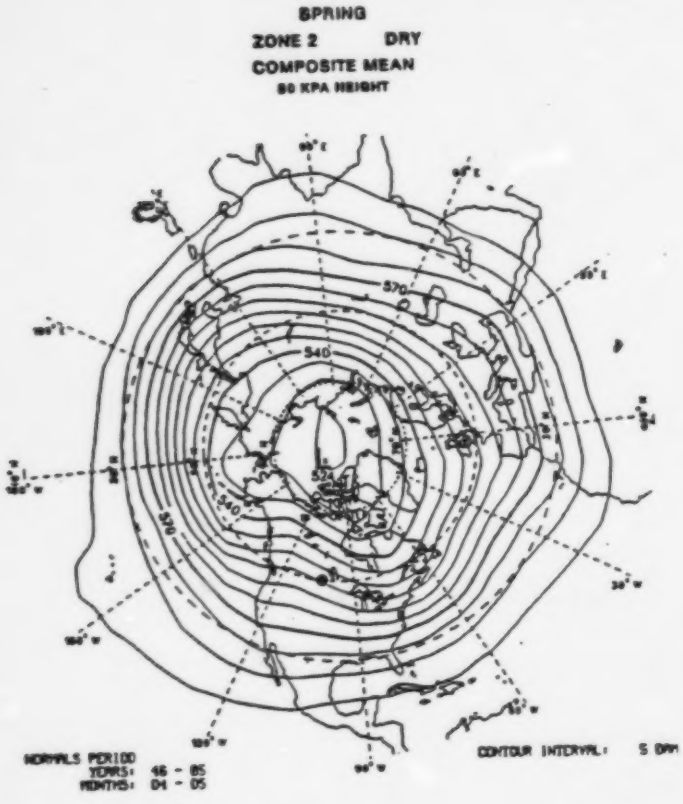
TABLE 3. Dates by Zone and Regime (WET/DRY) of the ranked qualifying cases for (a) spring and (b) early summer.

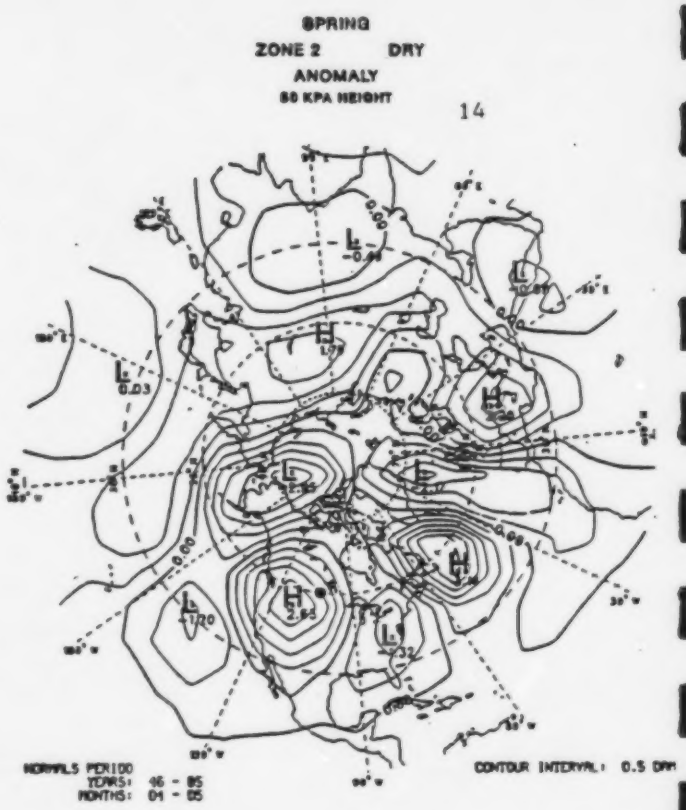
(a) SPRING

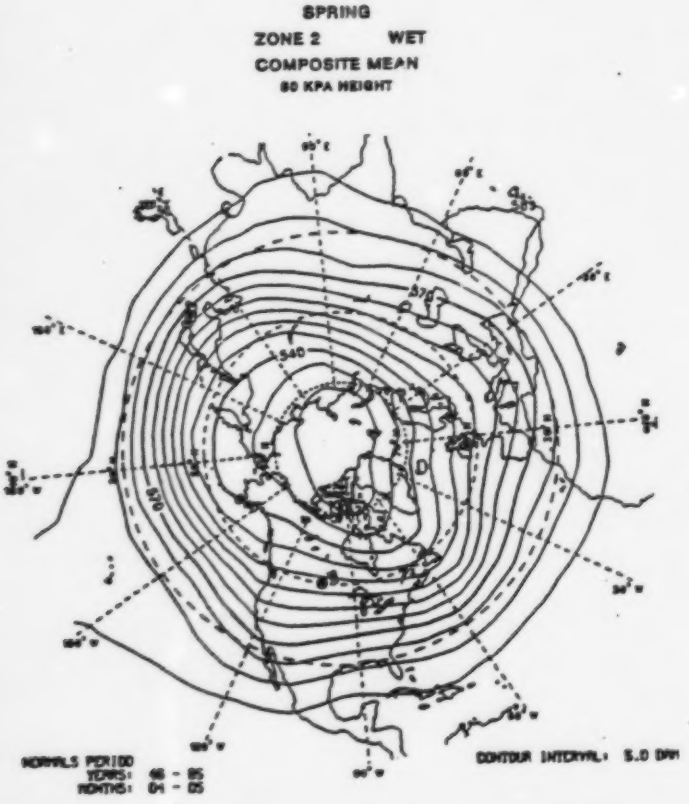
ZONE #2		ZONE #4		ZONE #5		ZONE #6		ZONE #7	
WET	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY
75 4	49 4	78 4	49 4	48 4	80 4	63 4	80 4	55 4	52 4
70 4	52 4	67 4	77 4	55 4	60 4	74 4	77 4	85 4	80 4
55 4	77 4	53 4	52 4	69 4	70 4	54 4	72 4	73 4	69 4
48 4	83 4	74 4	46 4	62 4	52 4	60 4	49 4	48 4	77 4
79 4	46 4	55 4	62 4	66 4	56 4	67 4	83 4	78 4	74 4
54 4	68 4	54 4	81 4	77 5	56 5	71 4	69 4	75 4	67 4
73 4	82 4	75 4	63 4	84 5	71 5	79 4	52 4	58 4	59 4
65 5	58 5	55 5	82 4	51 5	67 5	57 4	76 5	54 4	56 4
78 5	67 5	81 5	57 5	60 5	58 5	70 4	80 5	77 5	65 4
77 5	80 5	77 5	73 5	64 5	72 5	64 4	52 5	74 5	66 5
74 5	52 5	75 5	58 5	00 0	00 0	65 4	61 5	68 5	71 5
53 5	47 5	82 5	50 5	00 0	00 0	77 5	58 5	84 5	81 5
49 5	71 5	74 5	63 5	00 0	00 0	59 5	00 0	85 5	62 5
62 5	76 5	78 5	00 0	00 0	00 0	62 5	00 0	52 5	56 5
55 5	48 5	00 0	00 0	00 0	00 0	74 5	00 0	00 0	70 5
60 5	00 0	00 0	00 0	00 0	00 0	50 5	00 0	00 0	67 5
00 0	00 0	00 0	00 0	00 0	00 0	53 5	00 0	00 0	57 5
00 0	00 0	00 0	00 0	00 0	00 0	78 5	00 0	00 0	59 5
00 0	00 0	00 0	00 0	00 0	00 0	68 5	00 0	00 0	47 5
00 0	00 0	00 0	00 0	00 0	00 0	70 5	00 0	00 0	00 0
00 0	00 0	00 0	00 0	00 0	00 0	79 5	00 0	00 0	00 0
00 0	00 0	00 0	00 0	00 0	00 0	65 5	00 0	00 0	00 0

(b) EARLY SUMMER

ZONE #2		ZONE #4		ZONE #5		ZONE #6		ZONE #7	
WET	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY
53 6	61 6	70 6	85 6	56 6	82 6	84 6	61 6	70 6	64 6
76 6	67 6	63 6	77 6	83 6	63 6	76 6	72 6	65 6	58 6
71 6	74 6	53 6	74 6	71 6	66 6	83 6	62 6	66 6	69 6
47 6	58 6	51 6	61 6	73 6	55 6	81 6	59 6	83 6	77 6
75 6	79 6	65 6	83 6	65 6	67 6	77 6	79 6	76 6	67 6
54 6	82 6	83 7	55 6	61 6	77 6	62 7	76 7	73 6	59 7
63 6	68 6	55 7	49 6	55 7	58 7	58 7	74 7	63 6	84 7
82 7	85 7	50 7	67 7	82 7	85 7	82 7	85 7	71 7	47 7
46 7	51 7	82 7	47 7	83 7	65 7	53 7	60 7	50 7	60 7
70 7	67 7	66 7	73 7	77 7	59 7	48 7	54 7	68 7	75 7
63 7	79 7	00 0	84 7	64 7	84 7	00 0	00 0	82 7	00 0
48 7	60 7	00 0	85 7	57 7	00 0	00 0	00 0	76 7	00 0
83 7	59 7	00 0	00 0	00 0	00 0	00 0	00 0	00 0	00 0
50 7	84 7	00 0	00 0	00 0	00 0	00 0	00 0	00 0	00 0
00 0	47 7	00 0	00 0	00 0	00 0	00 0	00 0	00 0	00 0







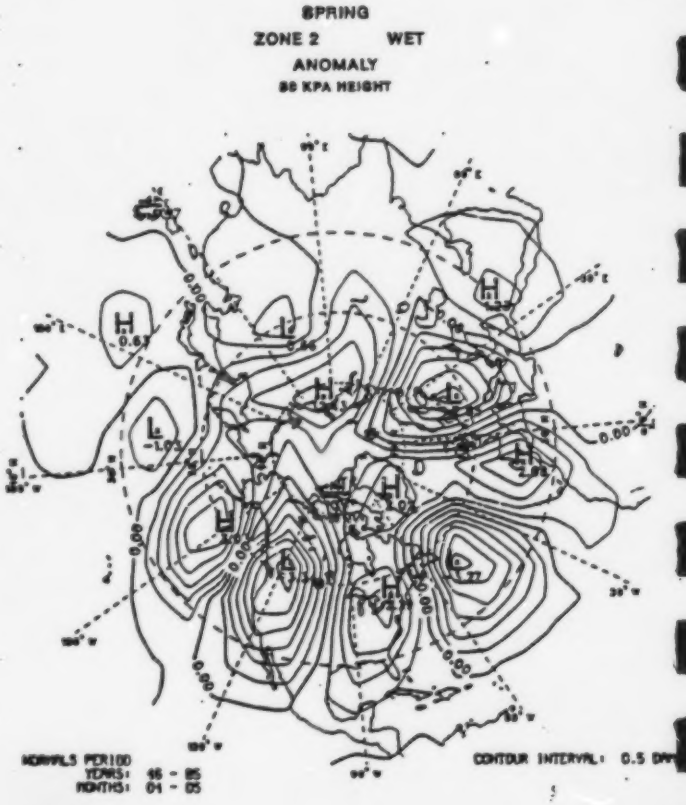


FIGURE 4. (a) Composite mean 50kPa height for ZONE 2 DRY cases in Spring.
(b) Anomalous 50kPa height field for ZONE 2 DRY cases in Spring.
(c) As in (a) except for WET cases.
(d) As in (b) except for WET cases.

SPRING

DIFFERENCE 50 KPA HEIGHT

ZONE 2 DRY LESS ZONE 2 WET

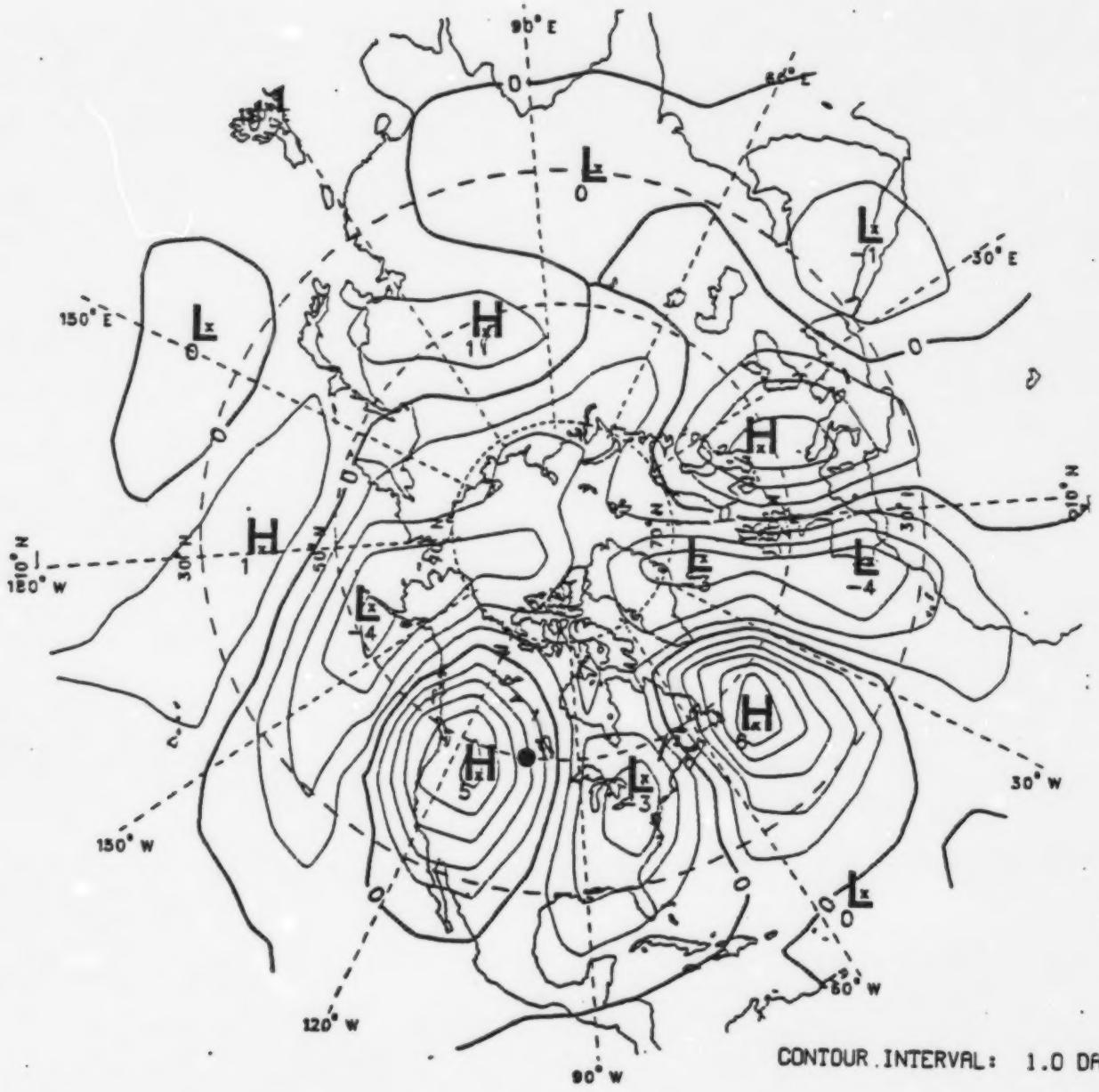
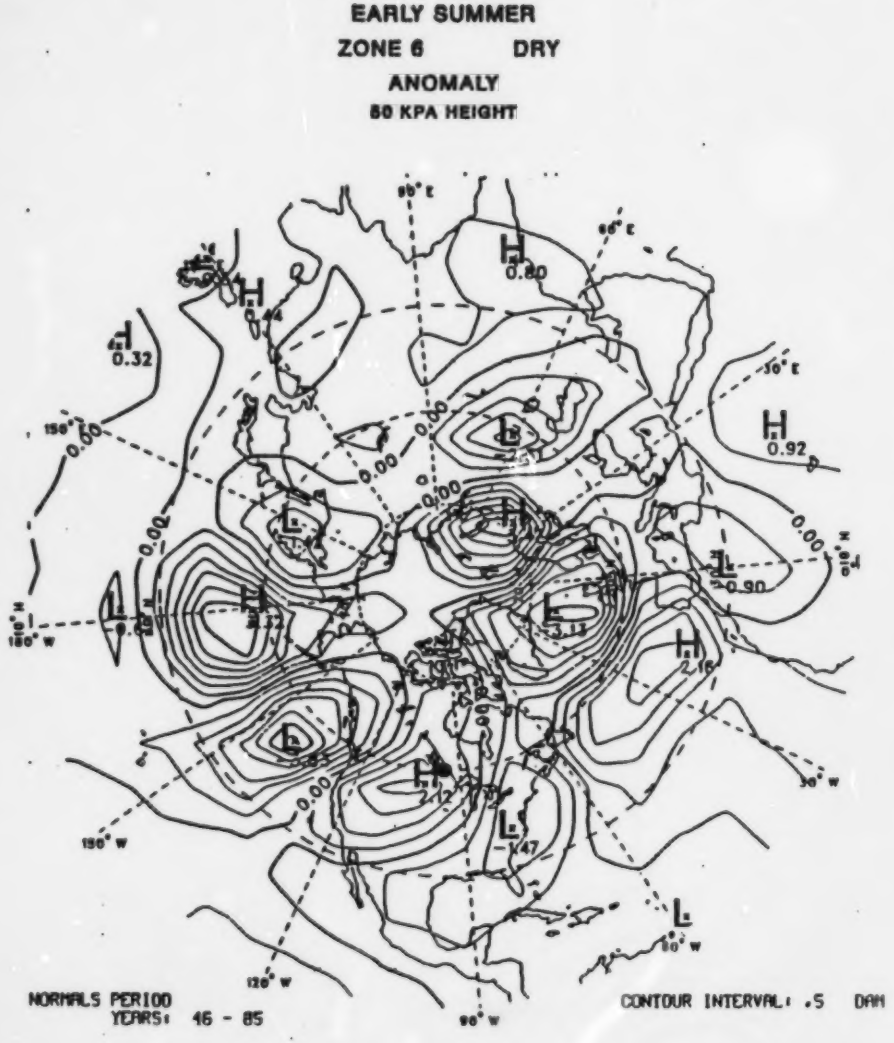


FIGURE 5. Difference of 50kPa height, ZONE 2 DRY less ZONE 2 WET in Spring.



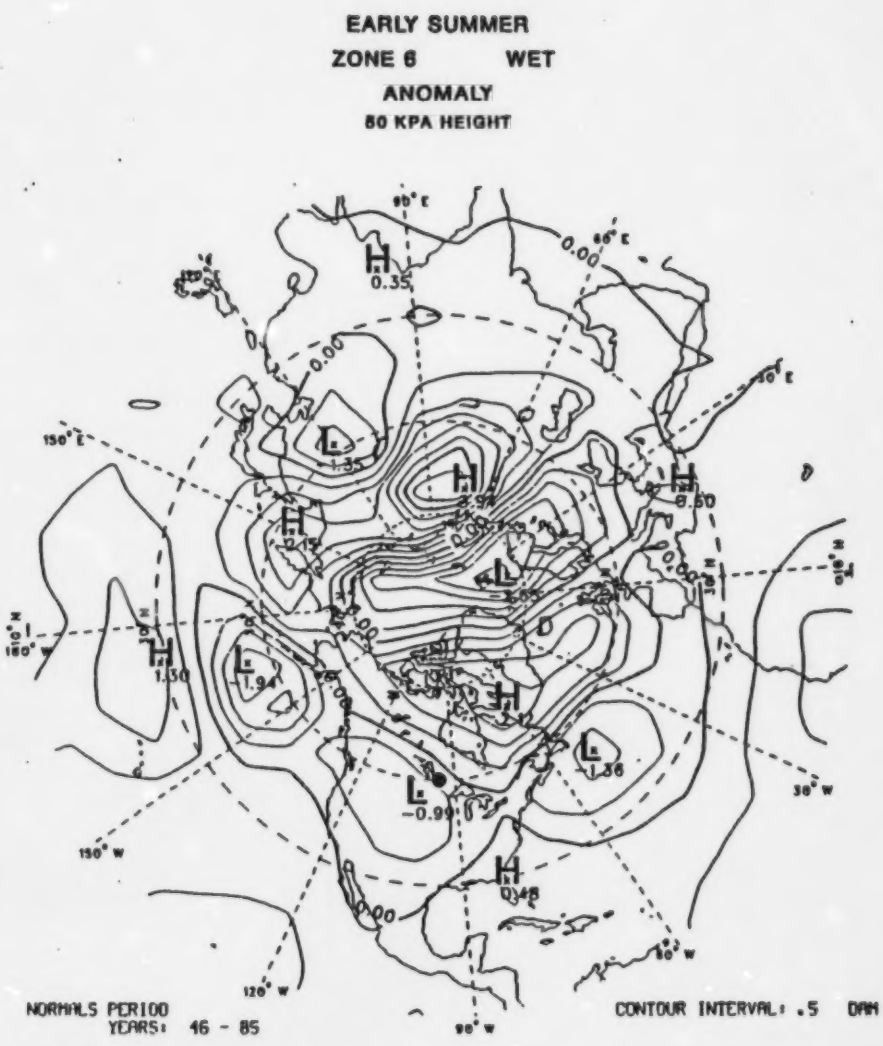


FIGURE 6. (a) Anomalous 50kPa height field for ZONE 6 DRY cases in EARLY SUMMER. (b) As in (a) except for WET cases.

direction, but also in the north-south. Again these are manifestations of opposite phases of the North Atlantic (NAO) and North Pacific (NPO) oscillations.

In all, there were 150 anomaly fields generated (5 zones, 5 seasons, 2 categories, 2 pressure levels and one thickness). All 40 fields corresponding to the SPRING and EARLY SUMMER, will be found in Appendix 1. The remaining 90 fields for the other three seasons, are available on request from the Hydrometeorological Research Division of the Canadian Climate Centre.

We compared the 50kPa level anomaly fields with their counterparts in the Namias (1981) 70kPa Teleconnection Atlas, and found a remarkable consistency. For example, Figure 6a, shows that the average 50kPa positive anomaly centre associated with dry Junes or dry Julys in southeastern Manitoba, is located near 45N 105W. The 70kPa Summer teleconnection pattern corresponding to that target point is shown in Figure 7, and the similarity with Figure 6a is unmistakable. In the eastern North Pacific Ocean for example, note that the -3.83 dam negative anomaly centre of Figure 6a at 42N 140W coincides with the negative correlation centre of Figure 7. Over the Atlantic, the positive anomaly axis oriented east-west along 43N is close to the positive correlation axis of Figure 7.

7.2 Synthesis and Interpretation of Composite Anomaly Field Attributes

Since the focus of this study is on the growing season, we systematically examined all the composite anomaly fields for SPRING and EARLY SUMMER and documented many of their salient commonalities. A summary of the results for SPRING is displayed in Table 4, and for EARLY SUMMER in Table 5. These tables should be used in conjunction with the teleconnection schematic of Figure 1. Phases of the NPO and the NAO are indicated by positive and negative signs determined in the following way:

The sign (positive or negative) of the NPO is determined by differencing the 50kPa height, 60N less 40N, at the following longitudes:

West Pacific Sector, 165E.
East Pacific Sector, 165W.

The sign of the NAO is determined by differencing the height, 60N less 40N , at the following longitudes:

West Atlantic Sector, 45W.
East Atlantic Sector, 15W.

The arrowheads of Figure 1 are located at the

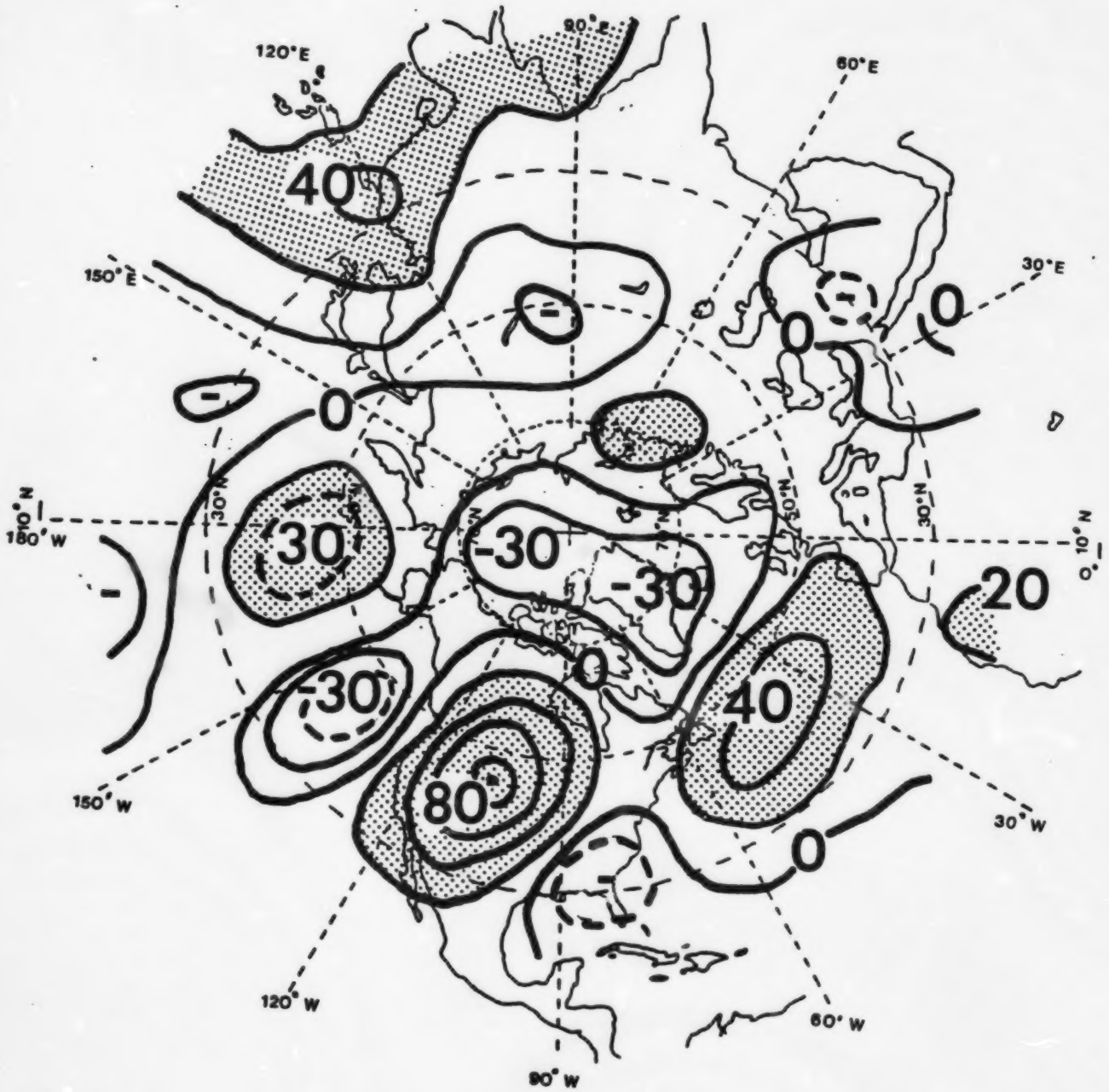


FIGURE 7. Contours define the field "teleconnections" obtained by correlating height anomaly at 45N 105W with all other grid point values of 70kPa height around the Northern Hemisphere. Based on summer months (June, July, August) over the period 1951-1980. Adapted from Namias, 1981.

TABLE 4. Composite Anomaly Field Attributes, SPRING.

TELECONNECTION PATTERNS AT 50 KPA FOR SPRING

ZONE	REGIME	ANOMALOUS WIND		NPO		PNA		NAO		REMARKS: significantly amplified anomalies, blocking, prototype dates, etc.
		100KPA	50KPA	WEST	EAST	Centre of nearest anomaly		WEST	EAST	
6	DRY	260	360	- -	- -	+	50N 105W	-	-	Persistent blocking over Wrn Canada occ'n blkg [1]NSU. (Prototypes: Apr., May 1980).
50N 97W	WET	130	200	+	+	-	45N 115W	+	+	Spring-time blocking anomaly pattern over North Atlantic.
2	DRY	280	300	-	- -	+	45N 110W	-	-	Strong mid-latitude westerlies.
50N 102W	WET	090	180	+	-	-	50W 120W	+ +	-	Blocking North Hudson Bay and Baffin Isl.; also over NSU.
4	DRY	270	280	-	-	+	40N 110W	- -	-	Strong mid-latitude westerlies amplified (+)ve Mid Pacific anomaly 47N 180W.
50N 110W	WET	090	160	+	+	-	40N 120W	+	+	Strong blocking NE Atlantic (Prototype: April 1978).
5	DRY	270	280	- -	- -	+	50N 120W	-	-	Above normal westerlies 50-55N (see May 1956 for a prototype).
55N 115W	WET	090	130	+ +	+ +	-	48N 130W	-	+	Very strong Mid-Pacific blocking (+)ve anomaly 55N 180W. (Prototype: Apr., 1948).
7	DRY	250	320	I	I	+	50N 115W	- -	-	Anomalies much attenuated except Baffin Isl.
52N 102W	WET	090	160	+	+	-	50N 120W	+ +	+	Blocking N. Pac., Baff. I., N. Atl (+) Anom 55N 180W. (Prototype Apr, May '55)

1 - NSU - Northern Soviet Union

TABLE 5. Composite Anomaly Field Attributes, EARLY SUMMER.

TELECONNECTION PATTERNS AT 50 KPA FOR EARLY SUMMER

ZONE	REGIME	ANOMALOUS WIND		NPO		PNA		NAO		REMARKS: significantly amplified anomalies, blocking, prototype dates, etc.
		100KPA	50KPA	WEST	EAST	Centre of nearest anomaly		WEST	EAST	
6	DRY	260	330	-	-	+	45N 105W	-	- -	Strong westerlies 50N. Prototype: June 1961 Amplified positive anomaly 45N 170W.
50N 97W	WET	160	140	+	+	-	45N 105W	+	+	Blocking over Baffin Isl. and W. Atlantic. (Prototype: June 1983).
2	DRY	270	340	-	+	+	45N 120W	-	-	Amplified positive anomaly 45N 170W. (compared with zone 6 DRY; see June 1961).
50N 102W	WET	090	150	-	-	-	47W 130W	+	+	High arctic blocking. (Prototype: July 1982).
4	DRY	I	270	+	-	+	46N 120W	I	I	Amplified positive anomaly 45N 170W. (c.f. zones 6 & 2 dry; see June 1985)
55N 110W	WET	120	140	+	I	-	34N 120W	-	+ +	Amplified negative anomaly 45N 180W. (Prototype July 1983).
5	DRY	270	280	I	I	+	50N 135W	I	+	Amplified (-)ve [1]NSU anomaly 65N 40E. (for prototype see July 1984).
55N 115W	WET	130	150	+	-	-	50N 140W	-	I	For prototype see July 1983.
7	DRY	310	340	I	+	+	51N 122W	-	+	For prototype see July 1984.
52N 102W	WET	090	120	+	I	I	-- --	-	+	Strong blocking NW Europe centred 58N 10E; amplified (-)ve anomaly 45N 180W.

1 - NSU - Northern Soviet Union

intersections defined above. Double entries of a sign indicate stronger north-south contrast relative to a single sign entry. When the contrast is very small (or ambiguous) the entry is designated "I" for indeterminate.

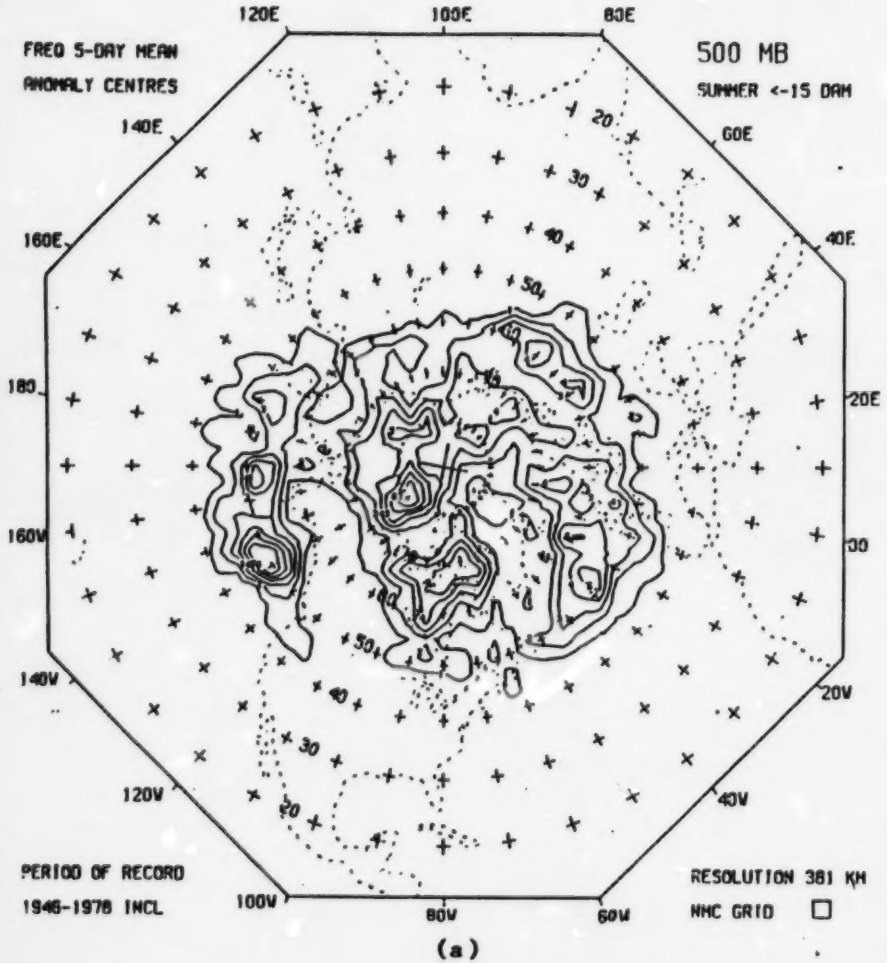
In the PNA column of the tabulation, we have entered the sign and location of the anomaly-centre nearest to the geometrical centre of the zone. (The latter is indicated by the solid circle on the composites and the locations are listed in Column 1 of both tables). To avoid repetition, it will be referred to simply as zone. We also tabulated the direction of the anomalous 100kPa and 50kPa circulation over the zone. The last column includes remarks concerning amplified anomalies of significance, blocking, strength of westerlies, and dates of prototypes.

Not unexpectedly it turned out that for both seasons the 50kPa anomaly field whose centre was nearest the zone corresponded to the mid-lobe of the PNA pattern. It is reasonable to regard this field as the primary large scale indicator of the circulation dynamics associated with the anomalous precipitation regime. In all cases but one, the sign of the anomaly centre was positive for the DRY cases and negative for the WET cases. (The single exception was zone 7 / WET / SUMMER, for which the PNA pattern was not discernible, and therefore the entry was labeled "I" i.e. indeterminate.)

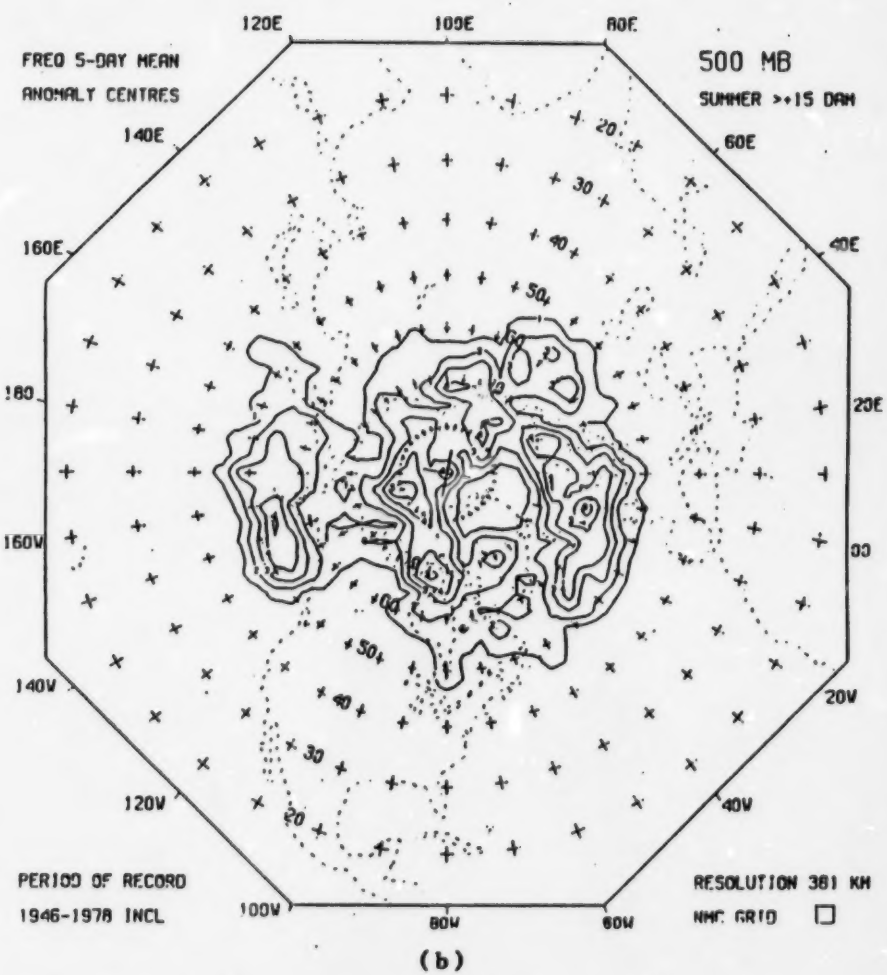
Also of interest is the fact that the mid-lobe centre of the PNA pattern was located on average, about 15 degrees of longitude to the west, and 5 degrees of latitude to the south of the zone. This finding is not inconsistent with the results of an investigation of the spatial distribution of persistent low-frequency positive and negative 5-day mean 50kPa anomaly centres in the Northern Hemisphere (Knox, 1982). He found that for both Spring and Summer, significant and persistent anomalies are rarely centred over the Canadian Prairies. The spatial frequency distribution of anomaly centres less than -15 dams, and greater than 15 dams, is displayed in Figures 8a and 8b respectively. There is a minimum of occurrence over a vast elongated area extending from the US mid-west plains northwestward over Alberta and Saskatchewan and into the Yukon, contrasted with a maximum of occurrence over the flanking northeast Pacific Ocean.

An examination of the AUTUMN and WINTER anomaly composites (not shown) indicates anomaly centre displacements which differ from those of SPRING and EARLY SUMMER. Details will be provided in a subsequent investigation.

Column three of both tables clearly indicates the strong connection between the direction of the anomalous



(a)



(b)

FIGURE 8. (a) Frequency of occurrence per 381 km square of all 5-day mean 50kPa anomaly centres less than -15 dams for the summer (June, July, August). Period of record 1946-1978 incl. Knox, 1982)
(b) Same as (a) except for centres greater than 15 dams.

wind, both at 50kPa and 100kPa and the category of the regime. Winds in the northwest sector are associated with the DRY regimes, while those in the southeast sector are associated with the WET.

It would also appear, from consideration of the change in wind direction from 100kPa (near the surface) to the 50kPa level, that baroclinicity is a strong characteristic of the WET months and to a lesser extent of the DRY. In the latter cases, the direction of the anomalous 100kPa wind is westerly, while that of the 50kPa wind is in the Northwest quadrant, an indication of differential warm advection, which, on average, is more marked over the central and eastern prairies. Moreover, from inspection it appears that for all of the DRY months, the source air mass from the North Pacific Ocean has been dried by subsidence and adiabatically heated in its descent of the eastern flank of the continental divide.

Examination of the SPRING WET cases in Table 4, discloses that the anomalous wind veers markedly with height, from generally easterly at 100kPa to southerly or southeasterly at 50kPa. For the WET cases in Table 5, EARLY SUMMER, there is (except for ZONE 6) a similar veering with height though of less magnitude. This would indicate that for the WET cases in both seasons, there is marked differential warm air advection in the lower half of the troposphere. In SPRING the easterly flow in the cold surface layer is superimposed by a southerly flow of moisture-rich air via the central USA. This is confirmed by a comparison between Figure 9 showing the 100kPa Anomaly (WET) for ZONE 2 and its counterpart at the 50kPA level, (shown in Figure 4d). Frontal lifting, lower tropospheric convergence, and orographic forcing on the easterly component in the lower levels, would combine to cause enhanced upward motion and therefore anomalous precipitation. In SPRING this precipitation can occur in the form of snow, and, in this event, can be more welcome than rain, particularly if the soil has not completely thawed.

It is worth emphasizing that the general rise of land from the east (Zone 6) to the west (Zone 4) approximates a gradient of 1:1000. This gradient is sufficient to force an easterly low level wind of about 40km/hr to produce a vertical motion of 1 cm/sec. Orographic forcing therefore, is a significant factor on the prairies. Indeed simulations by Raddatz (1975) have shown that orography accounts for some 13% of springtime precipitation over the plains increasing across southern Alberta to 37% in the foothills.

Surface heating during the two seasons, and particularly during the EARLY SUMMER, plays a strong

SPRING

ZONE 2 WET

ANOMALY

100 KPA HEIGHT

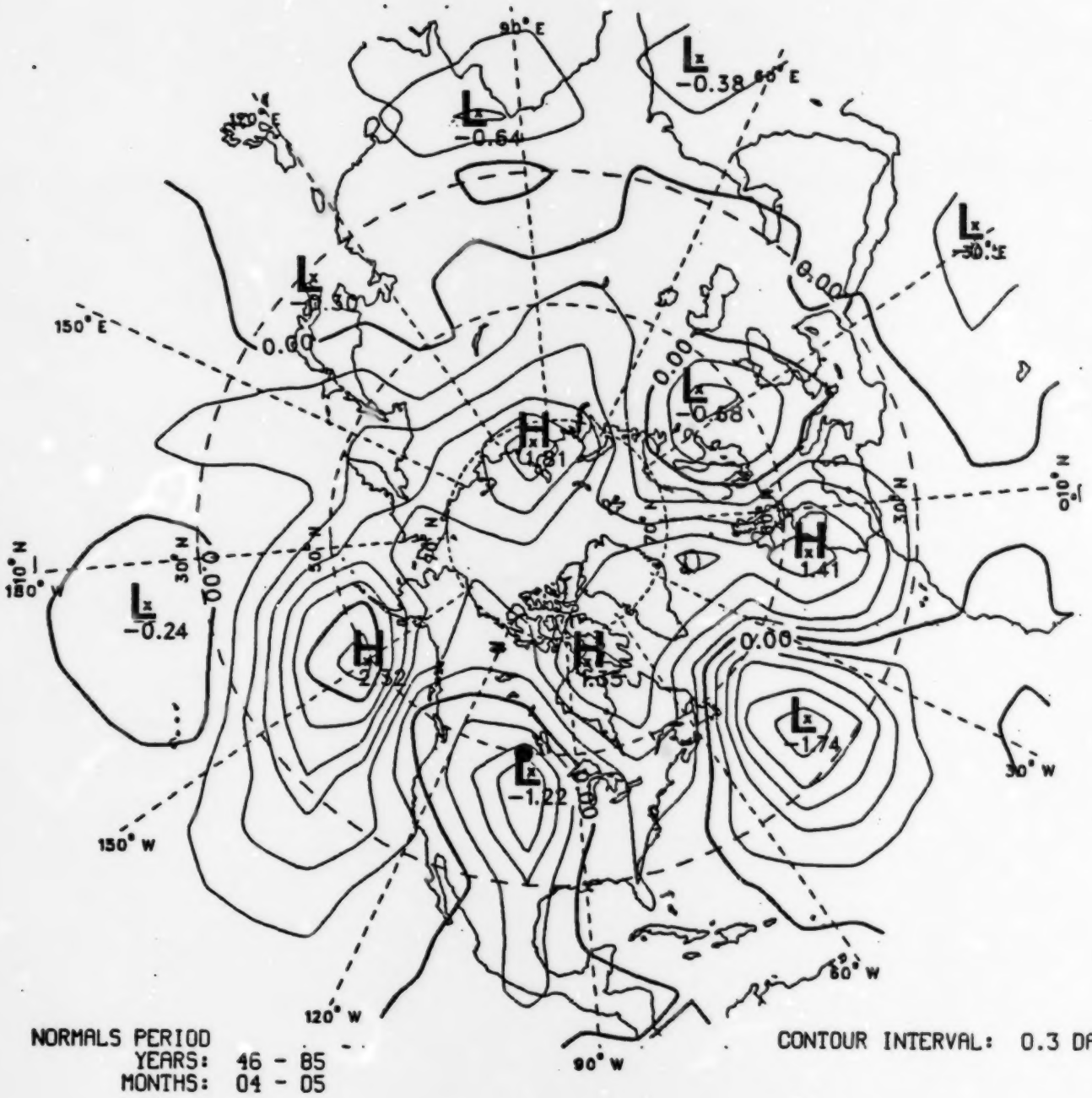


FIGURE 9. Anomalous 100kPa height field for ZONE 2 WET cases in SPRING.

reinforcing role during large scale circulation modes favouring upward vertical motion. It increases the likelihood of convective overturning, and therefore of meso-scale severe storms, with their associated heavy precipitation. This is evident from the profiles of Figure 2, where it is clear that for all zones, precipitation is positively correlated with surface heating.

7.3 Interpretation of the Phase sign of the NPO and NAO Oscillation

Perhaps the most striking result of this study is the strong relationship during the SPRING season between precipitation regimes over the Canadian Prairies, and the phase sign of the North Pacific and North Atlantic Oscillations. In the SPRING columns of Table 4, it is noted that almost invariably both sectors of the NPO and the NAO are in negative phase during DRY regimes and positive during WET.

There are a number of corollaries to this result which we have confirmed by examining a sample of prototype charts corresponding to dates selected from Table 3. During DRY regimes in SPRING, there are usually stronger than normal westerlies in the mid-latitudes of both oceans. This is the familiar high index mode for the western hemisphere circulation. As the PNA column of Table 4 shows, the downstream effect, for all zones, is an amplified positive anomaly over southwestern Canada or northwestern USA.

On the other hand, the WET regimes in SPRING are consistently associated with a western hemisphere low index scenario featuring considerable blocking in the higher latitudes simultaneous with regionally persistent cyclonic activity in the mid-latitudes. In these cases the blocking anticyclone is well removed (the order of 10,000 km) from the Zones. The latter, in fact, turn out to be where the cyclonic regimes reside. For example WET regimes in Zones 4, 6, and 7 are consistently associated with blocking over the northern North Atlantic, while Zones 5 and 7 are associated with blocking over the northern North Pacific, including the Bering Sea. The WET composites for Zones 2 and 7 also indicate a propensity for extensions of blocking into northeastern Canada (Baffin Island, Davis Strait, Northern Hudson Bay). This effect can be seen in Figure 4d. These results have also been confirmed by examining prototypes of the anomaly composites for the dates noted in the Remarks Column of Table 4.

Turning now to the EARLY SUMMER entries of Table 5 , we find them somewhat more difficult to synthesize. Perhaps this should not be surprising, for in the mid-latitudes,

June is a period of rapid attenuation of the planetary waves from their winter-time maxima, and by July they reach their minimum amplitude (Reiter and Westhoff, 1981). On the other hand, the amplitude of the long wave components 4, 5, and 6 increases, and therefore they assume a more dominant role in the circulation energetics. The result is that the large coherent areas characteristic of the Winter season NPO and NAO (and to some extent continuing on into Spring) have now broken down into smaller areas, a result also found by Namias (1982b). We can therefore hardly expect results showing the same degree of universality as was the case for SPRING. Zone 6 however, is a notable exception, as noted in the difference chart of Figure 10, (EARLY SUMMER, DRY less WET).

During DRY regimes, Zones 2, 4, and 6 feature an amplified mid-Pacific positive anomaly centred at 45N 170W. On the other hand during WET regimes, Zones 4 and 7 feature an amplified mid-Pacific negative anomaly at 45N 180W. In ten cases, the NPO and NAO were non-existent, and in the remainder of cases the sign was specific to the Zone/Regime.

8. PREDICTION

For obvious reasons there is a considerable literature on the subject of long-range prediction (one month to one season) and because of the well-known impact of drought on the Canadian Prairies, a descriptive survey of the present state of long-range prediction has recently been completed by Ripley (1988). Although it is a notoriously difficult problem, the remarkable improvement in Numerical Weather Prediction (NWP), combined with an increasingly better understanding of atmosphere-ocean-lithosphere interactions, has resulted in a perceptible increase in skill, particularly with regard to the prediction of monthly temperature anomalies. Because of the complex multi-scale processes giving rise to precipitation, its long range prediction is much less tractable, and so improvement in skill has been very gradual indeed.

Although this study is not intended to address the subject of long-range prediction of precipitation explicitly, it is hoped that the results will have some degree of application to the problem as it relates to the Canadian Prairies. We have focused the investigation on the more extreme groups of cases, that is to say, cases where the monthly precipitation is less than or greater than approximately one standard deviation. The results are summarized in Tables 4 and 5 and these give an indication of the kinds of development upstream over the North Pacific Ocean, or over North America, or downstream over the Atlantic, which might presage highly anomalous precipitation over the Canadian Prairies during the growing season months. In SPRING, for example, there is a consistency with regard

SPRING

DIFFERENCE 50 KPA HEIGHT

ZONE 6 DRY LESS ZONE 6 WET

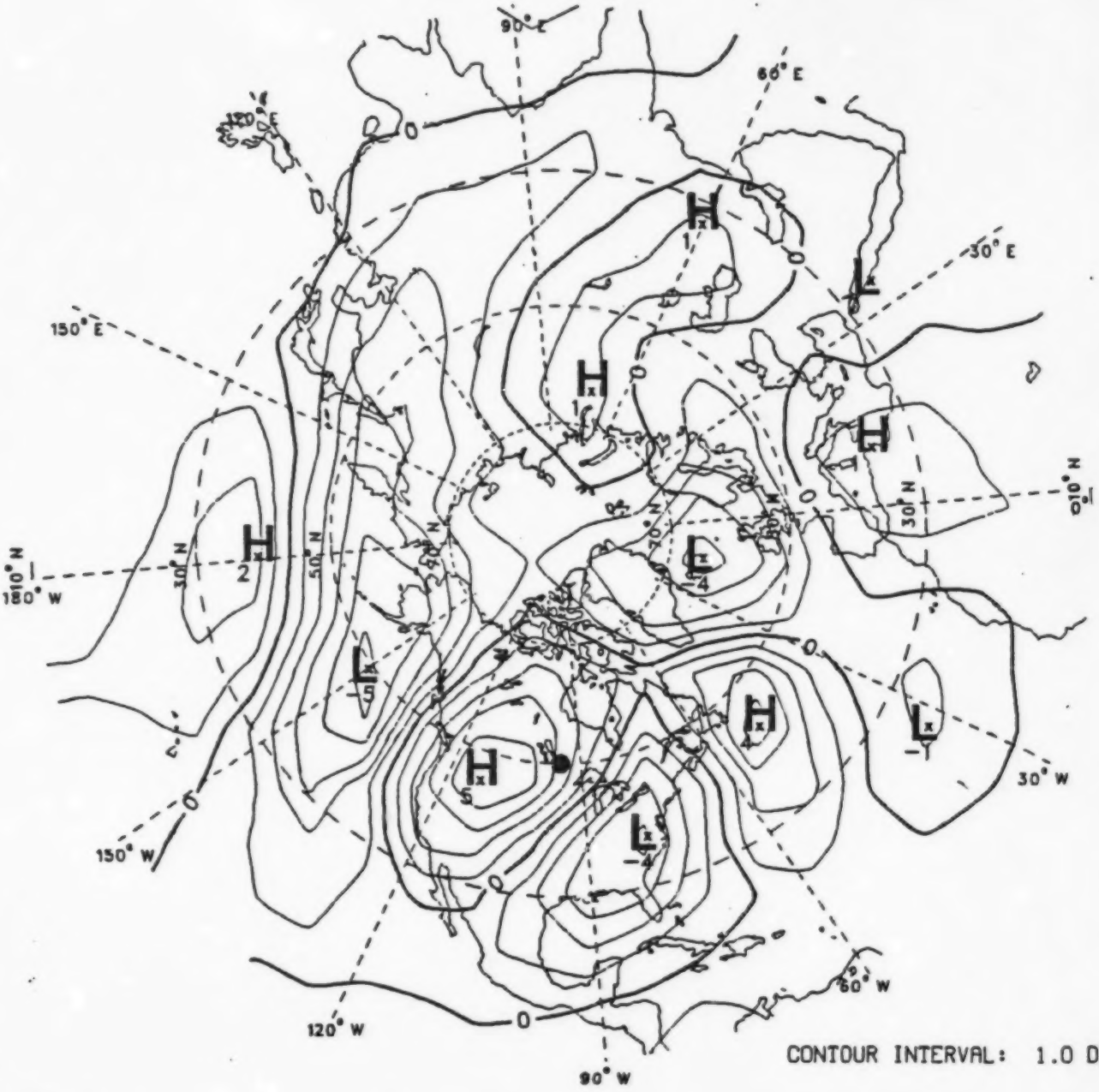


FIGURE 10. Difference 50kPa height Anomaly Zone 6 DRY less Zone 6 WET.

to the sign of the NPO, PNA, and NAO modes and the associated precipitation regimes over the Canadian Prairies. Dry regimes are clearly associated with abnormally strong westerlies in the Western Hemisphere, while wet regimes are associated with high latitude blocking in the manner indicated by Table 4. Time-averaged height anomalies identifiable as components of the teleconnection modes of Figure 1 should be monitored carefully to anticipate changes in sign, amplification, and latitude.

It should again be emphasized that Tables 4 and 5 present results for the SPRING and EARLY SUMMER only. Similar summaries could be prepared for the other three seasons because the corresponding series of composite-anomaly charts for each of the five zones, two regimes, and three pressure levels were prepared during the course of this study.

In any procedure designed to predict the monthly mean geopotential height at significant pressure levels, it is essential to heavily weight the Numerical Weather Prediction (NWP) output for the first five days of the month. Moreover some centres (e.g. the European Centre for Long Range Forecasting) have demonstrated useful residual skill in the NWP forecast mean for the second five days. It follows that long-range prediction monitoring, diagnostic and statistical procedures should take into account the NWP output, which to some extent provides a 10-day springboard into the month.

There still remains the problem of specifying the precipitation field from the height field prediction. It is understood that statistical techniques are being developed for application to Canada. In order to sharpen the precipitation predictions e.g. to identify where much above or much below areas are likely to be, these statistical procedures should be supplemented by results from diagnostic studies such as this one. For example, this study indicates that very wet and very dry months over a particular zone of the Canadian Prairies are associated with distinctive anomaly configurations in the 50kPa field of the Northern Hemisphere. Therefore, given a forecast monthly mean 50kPa height field and its associated anomaly pattern, it is suggested that a comparison with our results should assist in identifying areas where much above or much below normal precipitation is likely to occur during that month.

It should be noted that the contour interval chosen for our 50kPa Anomaly charts (derived from Composites of some 10 to 20 cases) was 0.5 dams. It is important, when comparing a particular Anomaly chart from the Appendix with the 50kPa Anomaly field for the current month, that the latter has been contoured at an appropriate interval to adequately define the field. For example, the current practice of the Canadian Climate Centre is to use a 5.0 dam interval for

contouring monthly mean anomaly charts. While this may be satisfactory for 5-day mean charts, it is too coarse for 30-day means. We suggest that, for the warm portion of the year it be changed to some value greater than 0.5 dams, of course, but substantially less than 5.0 dams as at present. We suggest testing 1.0, 2.0 dams for the warm part of the year, and 2.0, 3.0 dams for the cold. Such intervals will provide the field definition required for use with the composites.

9. CONCLUDING REMARKS

We have completed an analysis of the relationship between wet and dry months over the Canadian Prairies and contemporaneous anomalies in the Northern Hemisphere mid-and lower troposphere circulation, during SPRING and EARLY SUMMER. The anomaly fields arising from the composited charts clearly distinguish the circulations associated with the DRY and WET regimes, and also indicate significant differences from zone to zone. The fields are well defined, not only over western North America, but also over the North Pacific and the North Atlantic Oceans. The spatial relationship is usually consistent with the cross-correlation fields used to demonstrate teleconnections.

For the two seasons analyzed, the EUA pattern was weak, with the one exception of Zone 6 EARLY SUMMER (Figure 10). With this exception, it would appear that during the growing season, the relationship between Canadian Prairie 50kPa anomalies associated with anomalous precipitation, and contemporaneous 50kPa anomalies in the Eastern Hemisphere, is not very strong. However, this does not preclude the existence of significant relationships with the EUA pattern during one or more of the other three seasons.

High latitude blocking, sometimes including blocking over the Baffin Island area, was often associated with WET regimes over the Prairies. When Baffin Island blocking occurs, the semi-permanent NE Canadian Low is significantly displaced from its normal position with profound consequences on temperature and precipitation regimes over large portions of Canada, K-H.

It is probably not unreasonable to suggest that, if the goal is the prediction of highly anomalous precipitation regimes (DRY or WET), our map composites may be more useful at least for diagnostic purposes, than teleconnection fields constructed by cross-correlating the mid-tropospheric height anomaly at a target with height anomalies at grid points in the Northern Hemisphere.

Although we focused on the growing seasons, a wealth of anomaly-composites were also prepared for the LATE SUMMER, AUTUMN and WINTER, at the 50kPa and 100kPa levels and for

the 50kPa-100kPa relative topography (or thickness). Access to this material can be obtained through the authors.

It is suggested that consideration be given to a similar study of anomalous monthly mean precipitation over other characteristic areas of Canada. For example, one is already in process for regions of British Columbia, by one of the authors of this paper. Preliminary results from the latter, and also the results of Stidd, 1954, (who carried out a somewhat similar investigation for the individual states of the USA) would strongly suggest that we would find, for other parts of Canada, associated 100kPa and 50kPa circulation anomalies highly distinguishable from those for the Canadian Prairies.

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APPENDIX A.

50 kPa Height Anomaly Charts for Spring and Early Summer

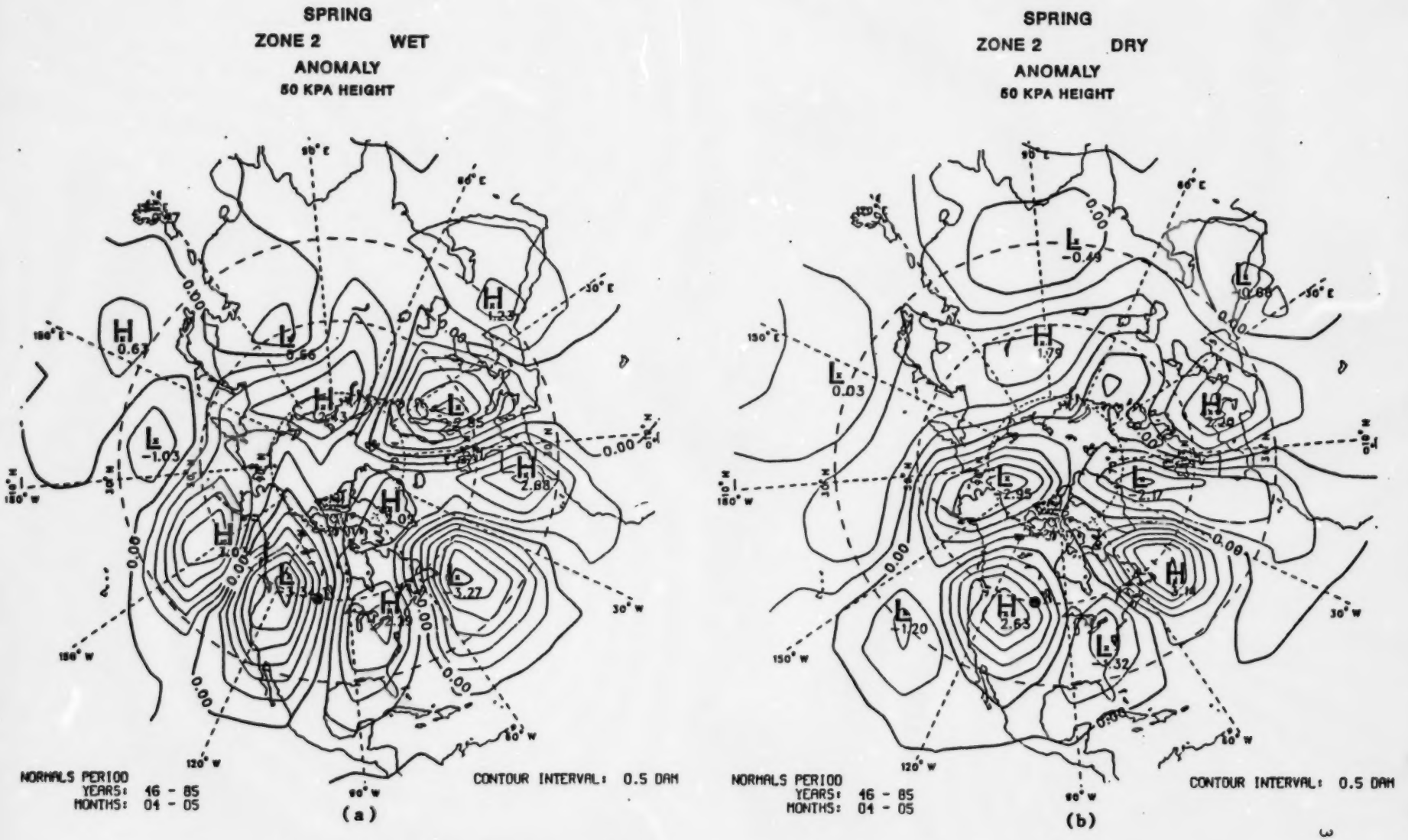

FIGURE A.1. 50kPa Height anomaly chart for Spring, Zone 2 for:
a.) wet and
b.) dry months.

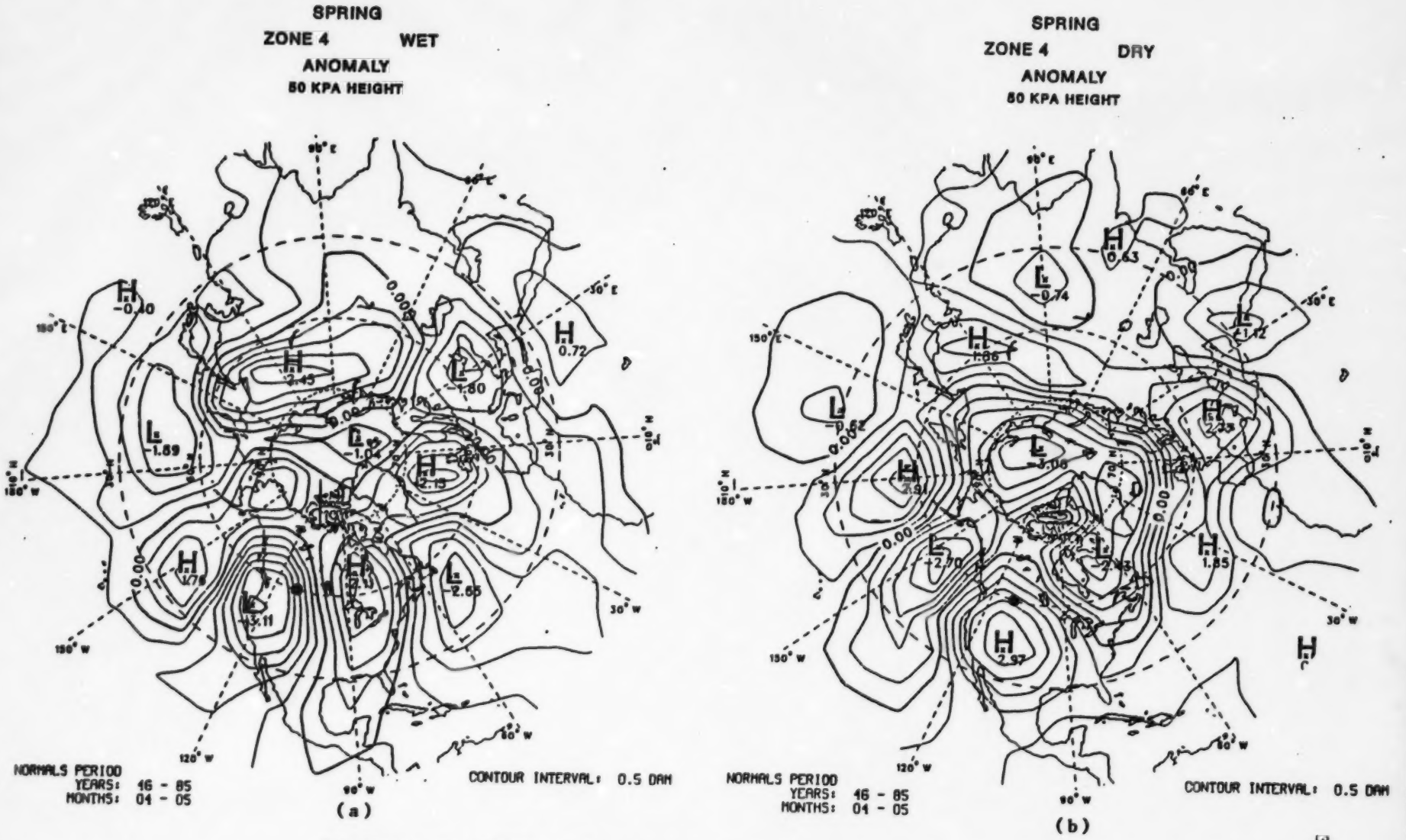

FIGURE A.2. 50kPa Height anomaly chart for Spring, Zone 4 for:
a.) wet and
b.) dry months.

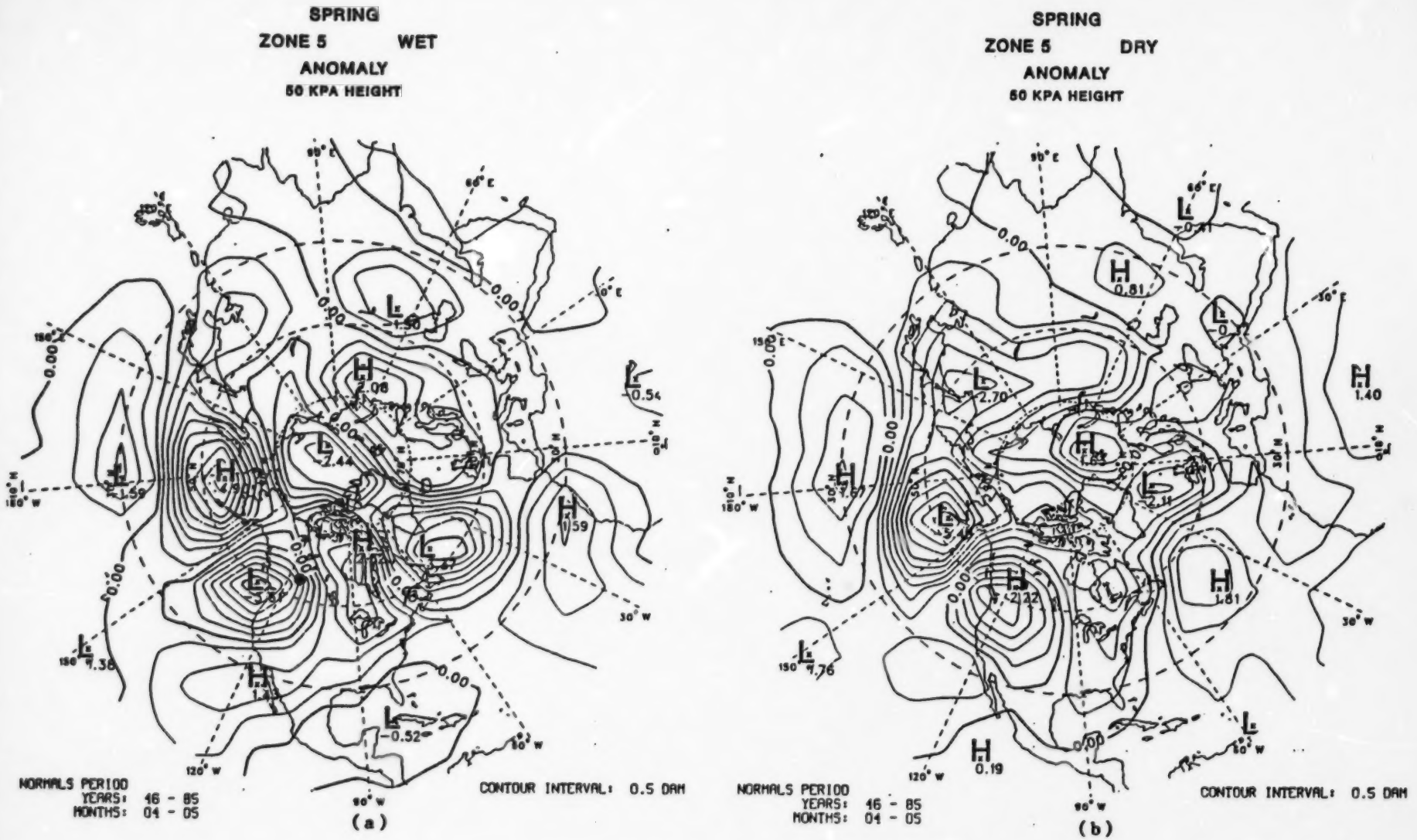

FIGURE A.3. 50kPa Height anomaly chart for Spring, Zone 5 for:
a.) wet and
b.) dry months.

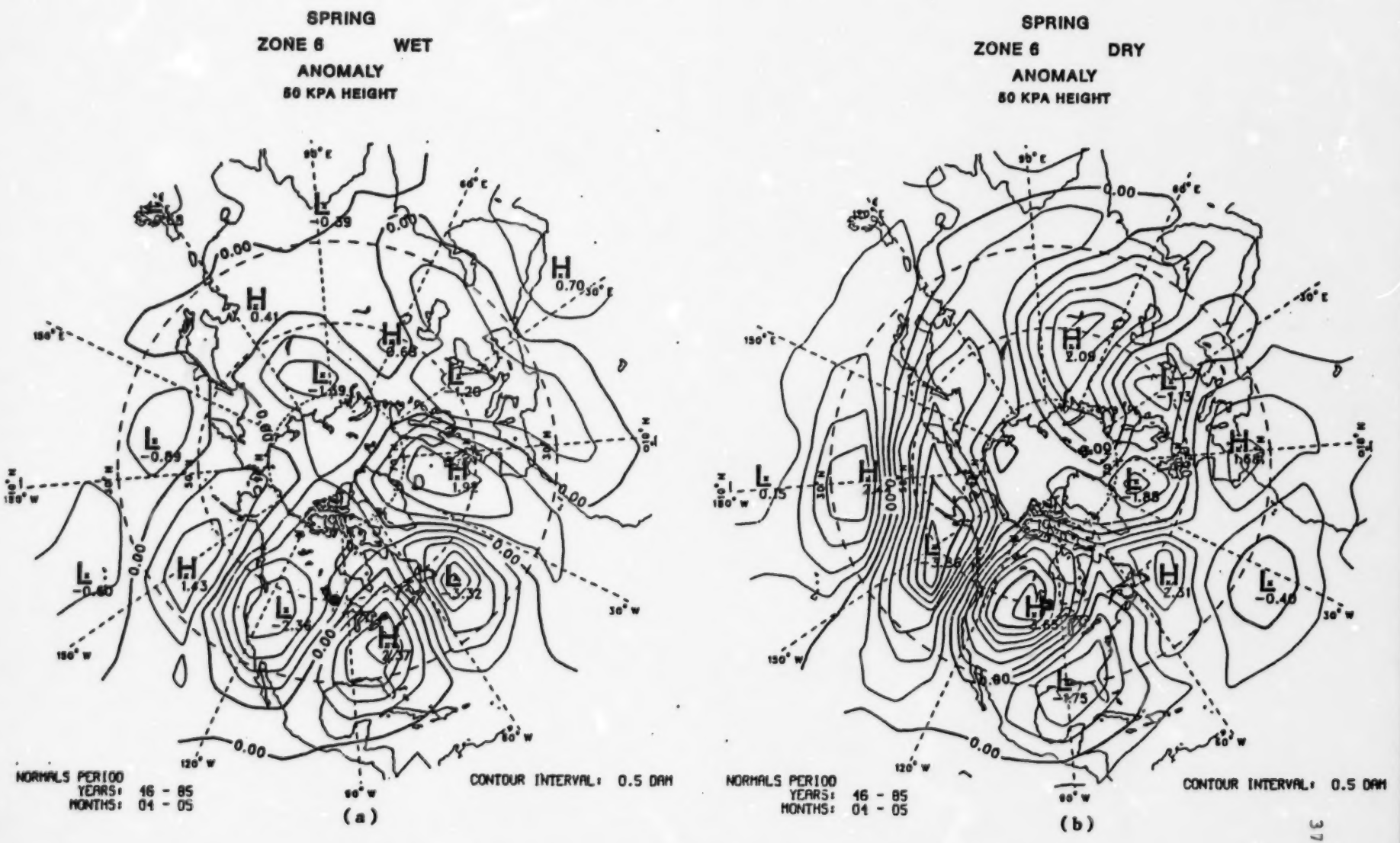

FIGURE A.4. 50kPa Height anomaly chart for Spring, Zone 6 for:
a.) wet and
b.) dry months.

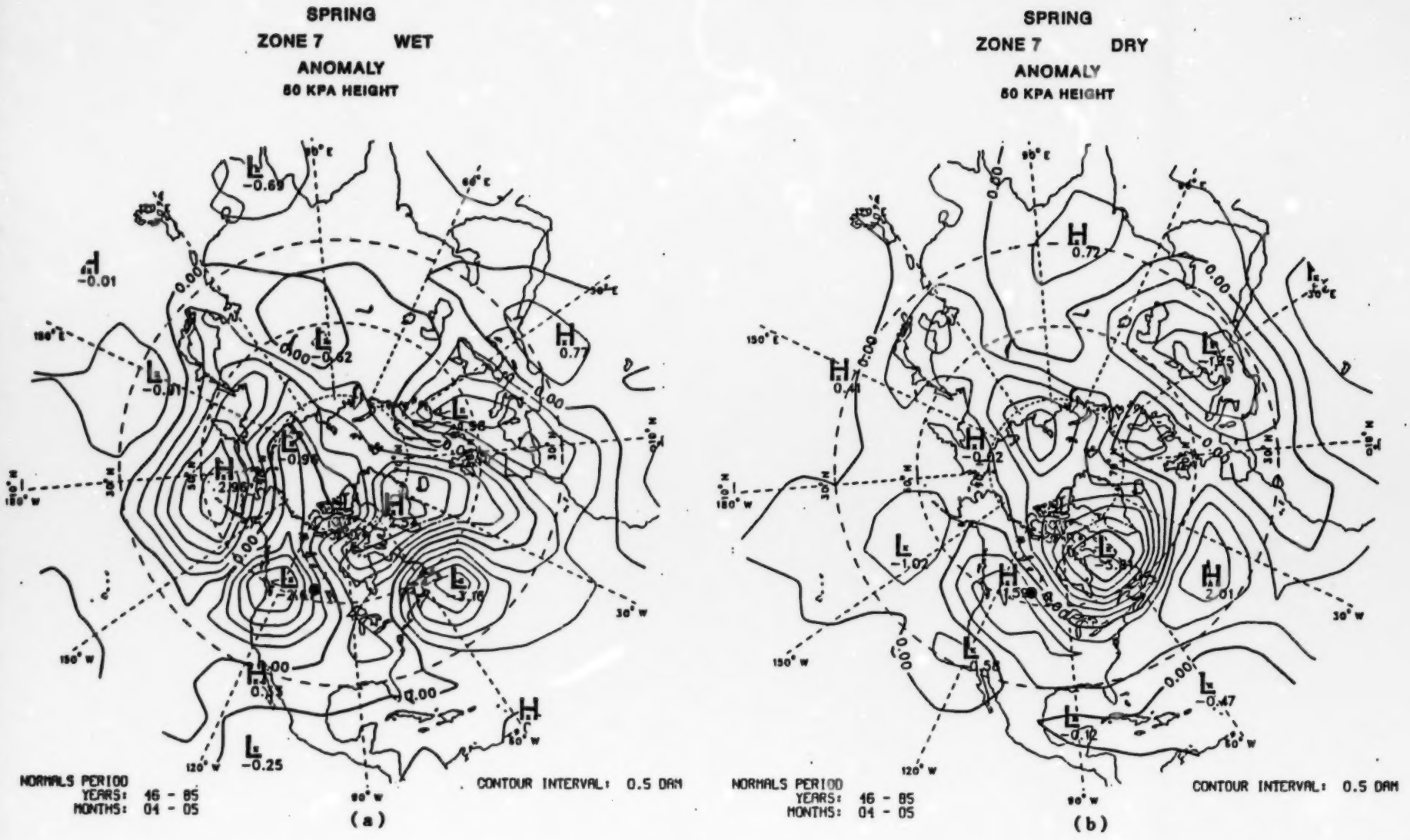

FIGURE A.5. 50kPa Height anomaly chart for Spring, Zone 7 for:
a.) wet and
b.) dry months.

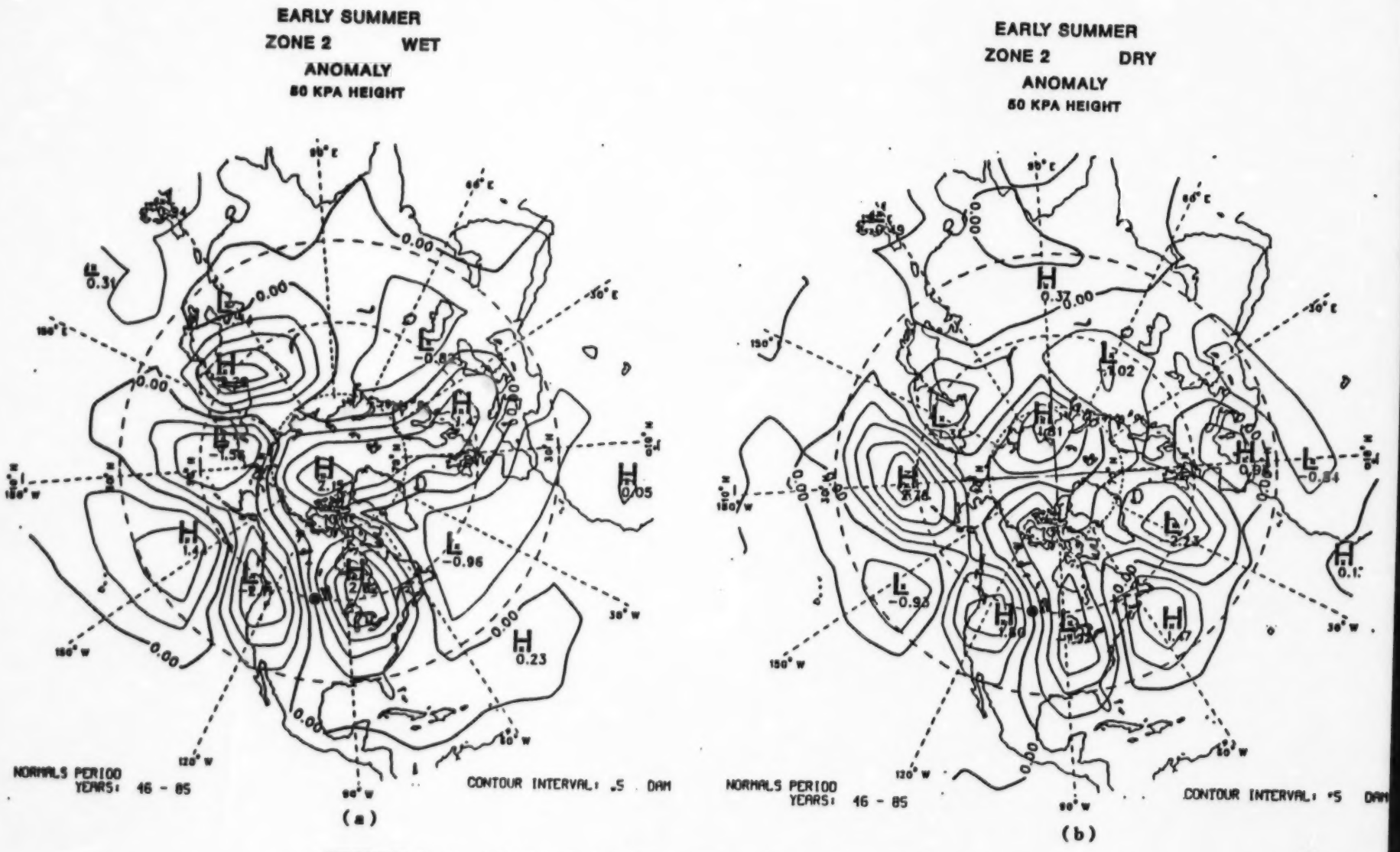

FIGURE A.6. 50kPa Height anomaly chart for Early Summer, Zone 2 for:

a.) wet and
b.) dry months.

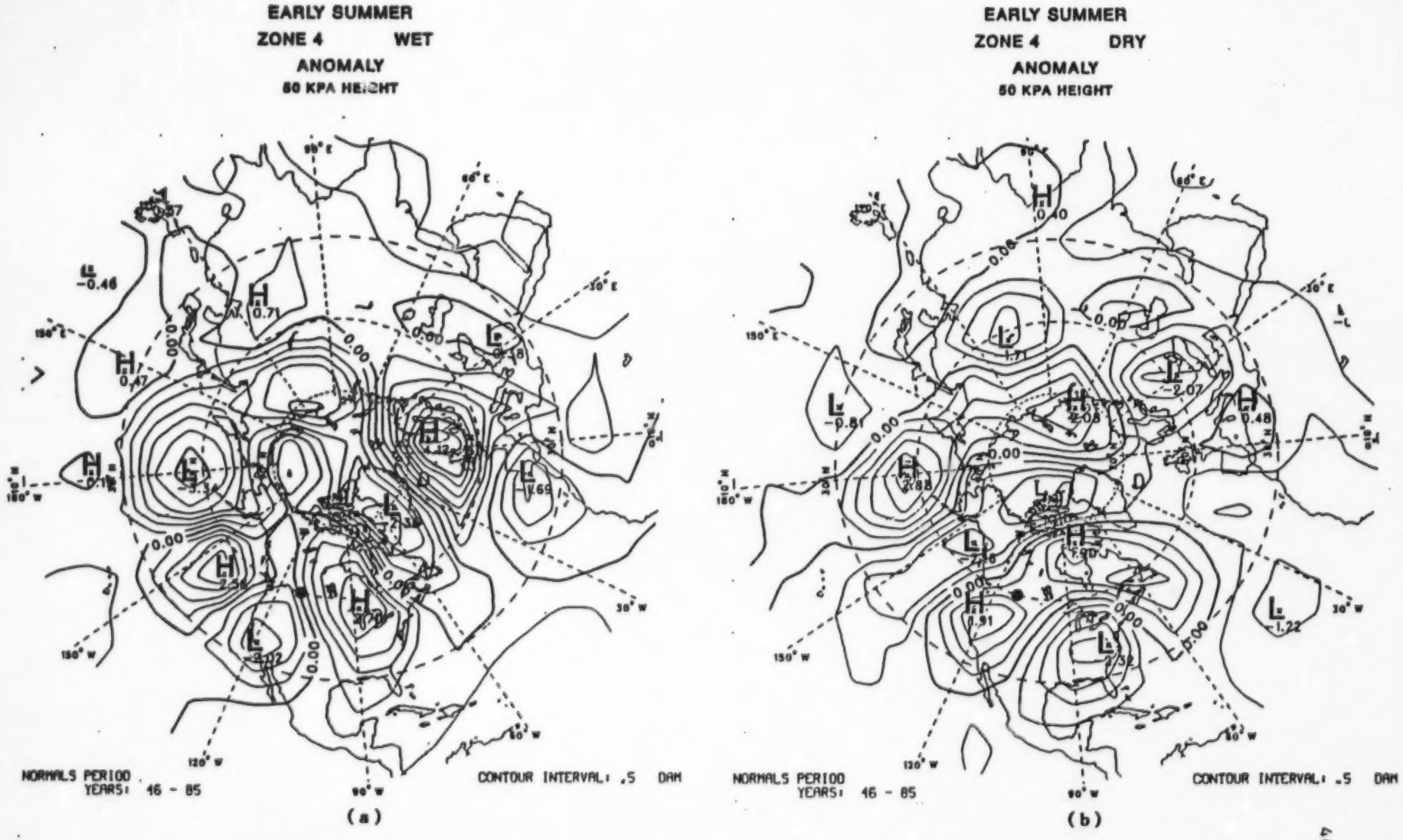

FIGURE A.7. 50kPa Height anomaly chart for Early Summer, Zone 4 for:

a.) wet and
b.) dry months.

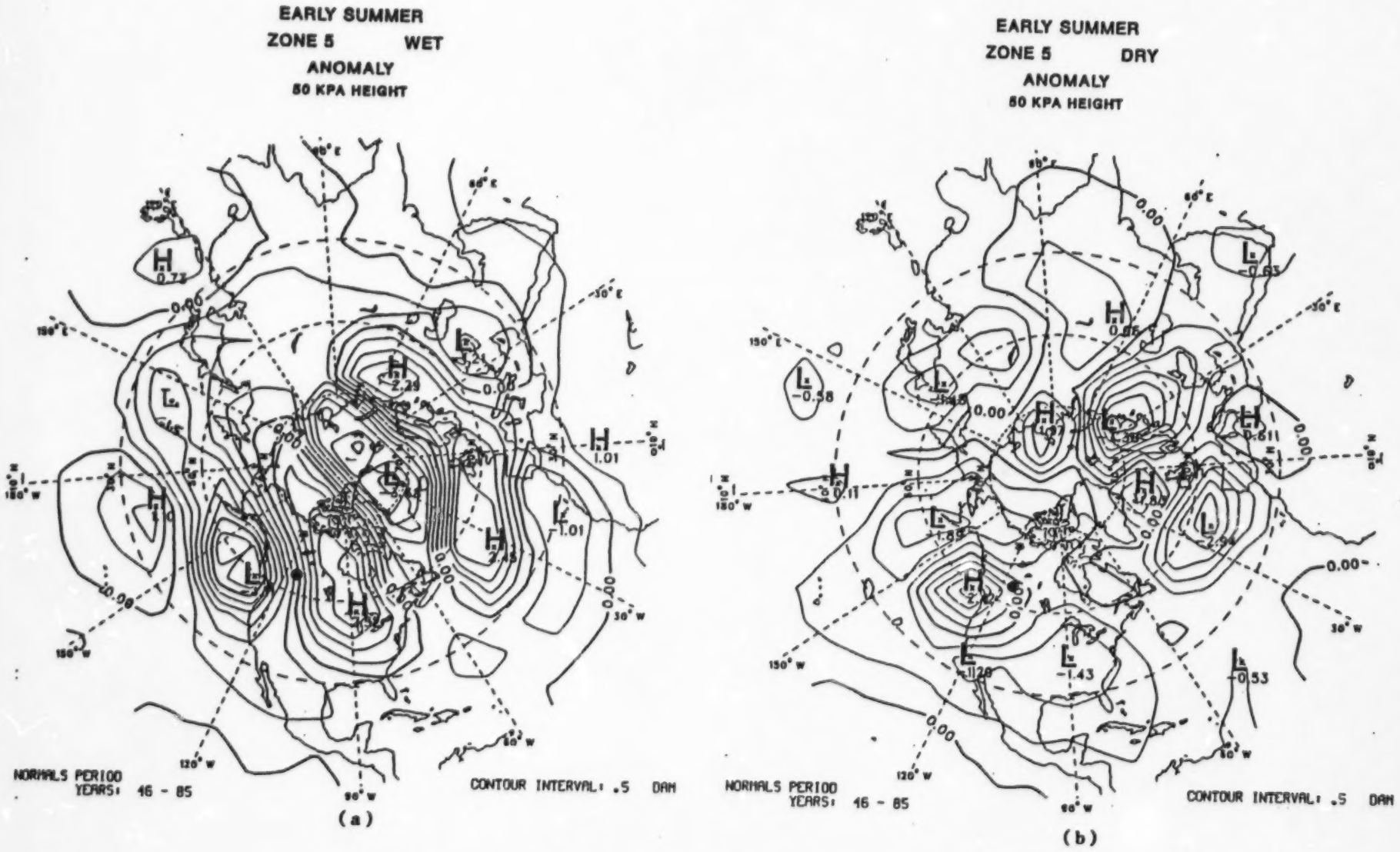

FIGURE A.8. 50kPa Height anomaly chart for Early Summer, Zone 5 for:

a.) wet and
b.) dry months.

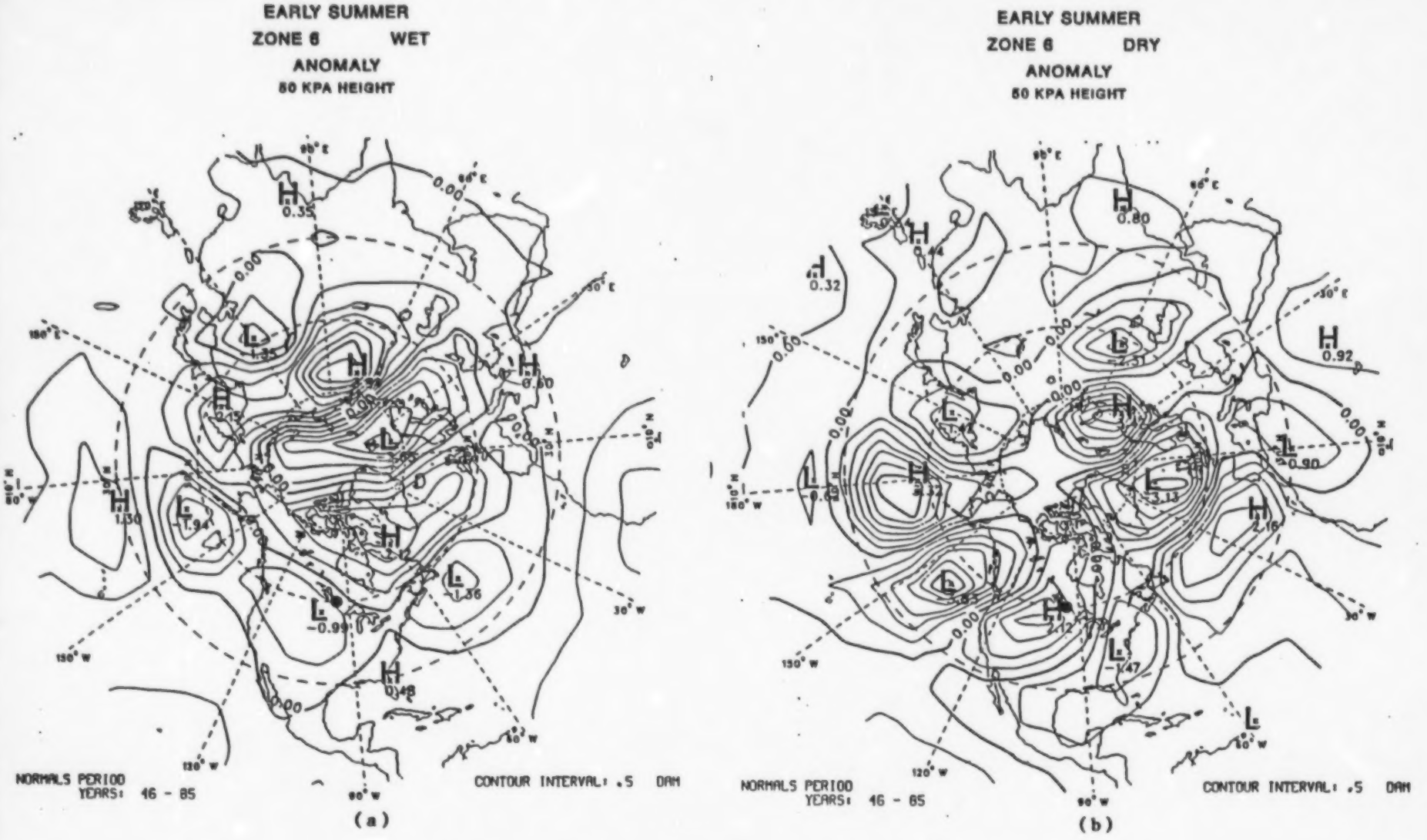

FIGURE A.9. 50kPa Height anomaly chart for Early Summer, Zone 6 for:

a.) wet and
b.) dry months.

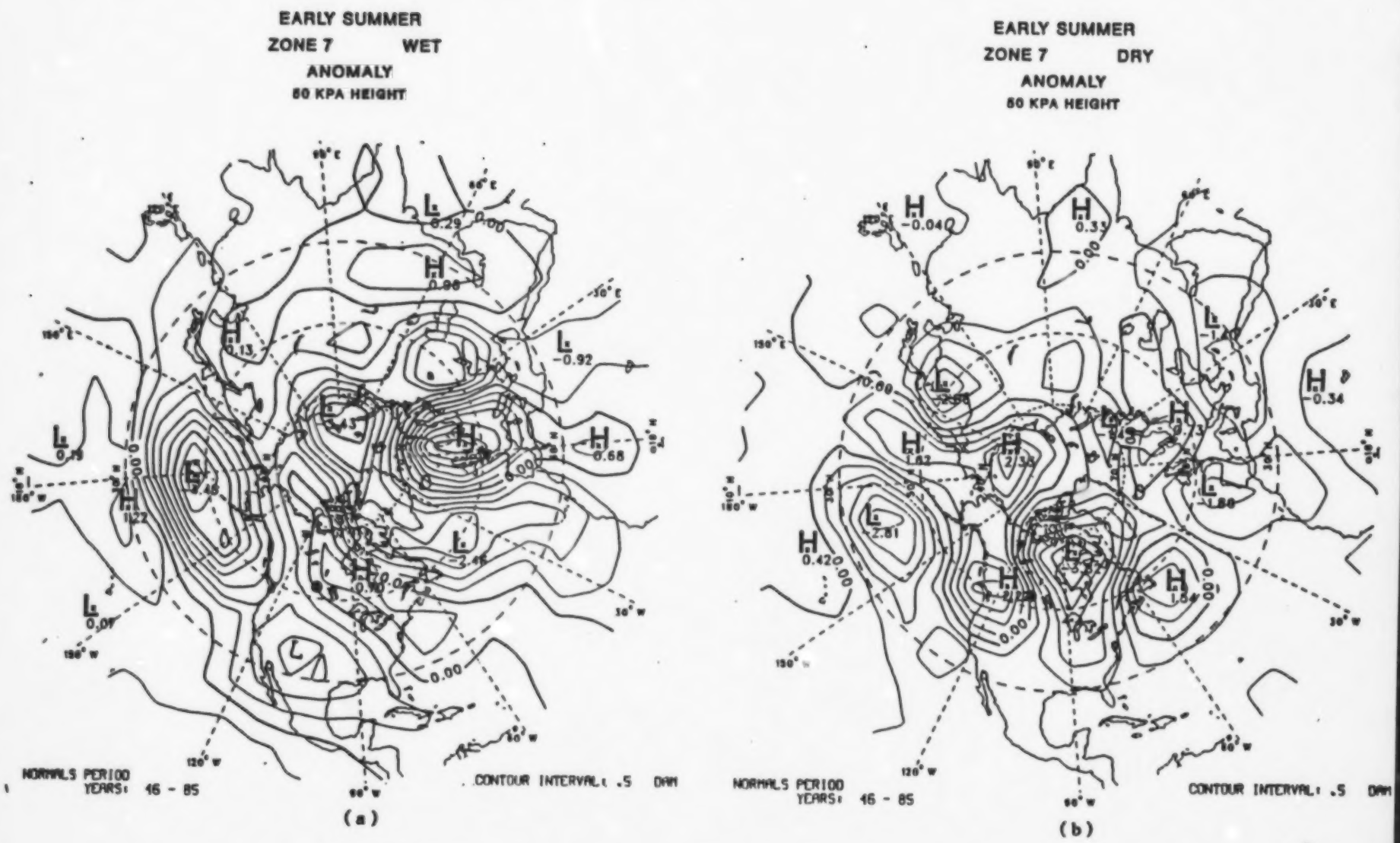

FIGURE A.10. 50kPa Height anomaly chart for Early Summer, Zone 7 for:

a.) wet and
b.) dry months.

APPENDIX B.

100 kPa Height Anomaly Charts for Spring and Early Summer

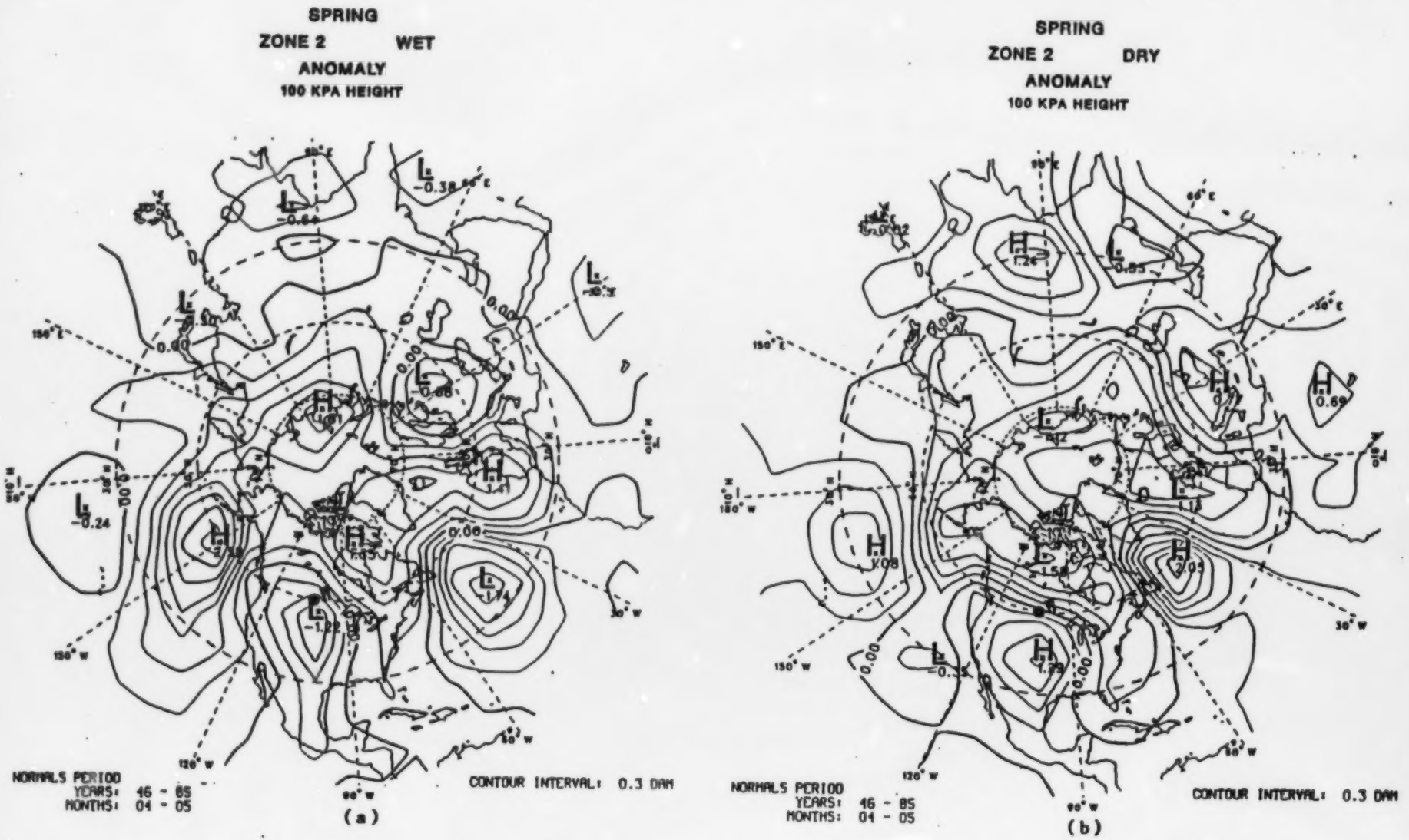

FIGURE B.1. 100kPa Height anomaly chart for Spring, Zone 2 for:
a.) wet and
b.) dry months.

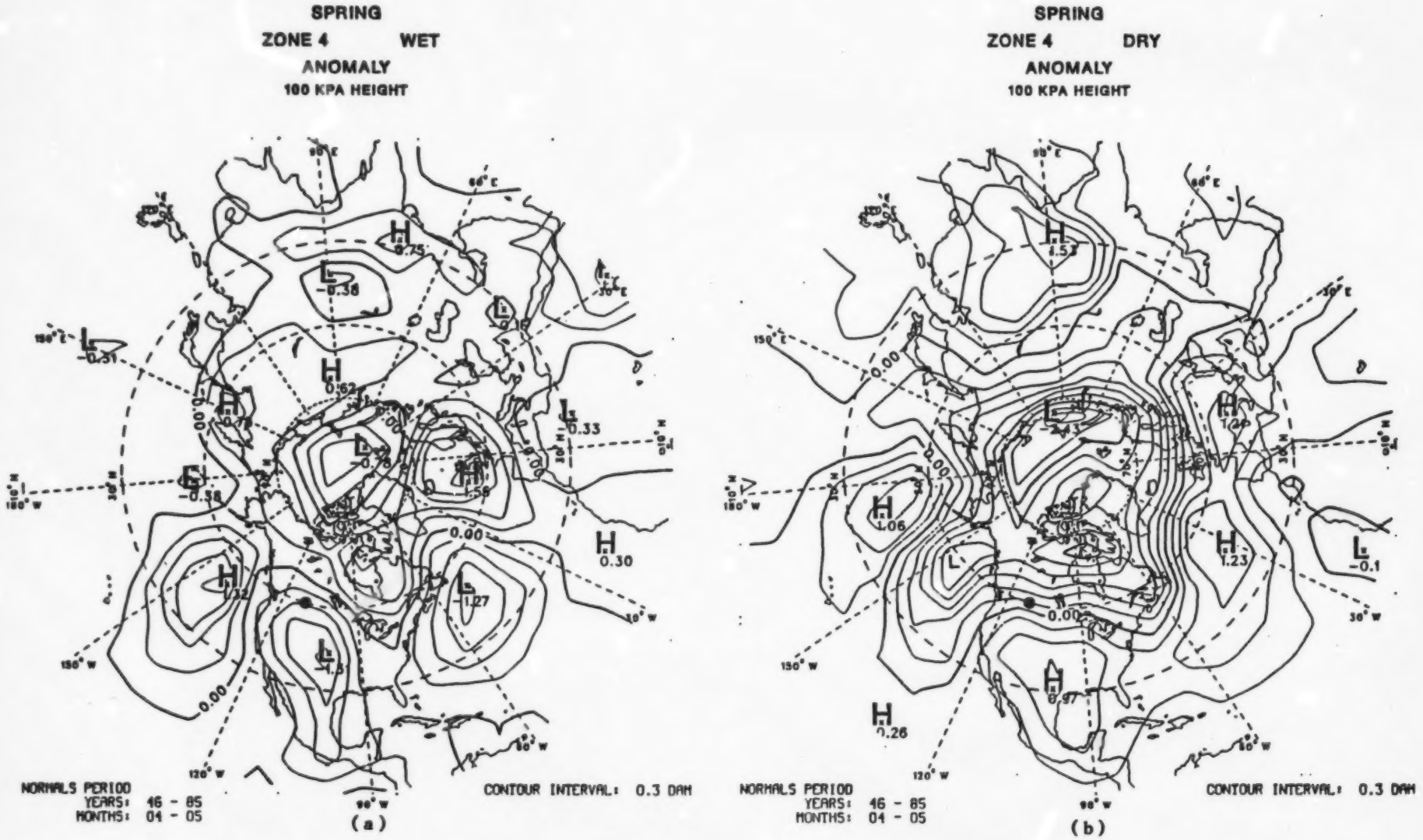

FIGURE B.2. 100kPa Height anomaly chart for Spring, Zone 4 for:
a.) wet and
b.) dry months.

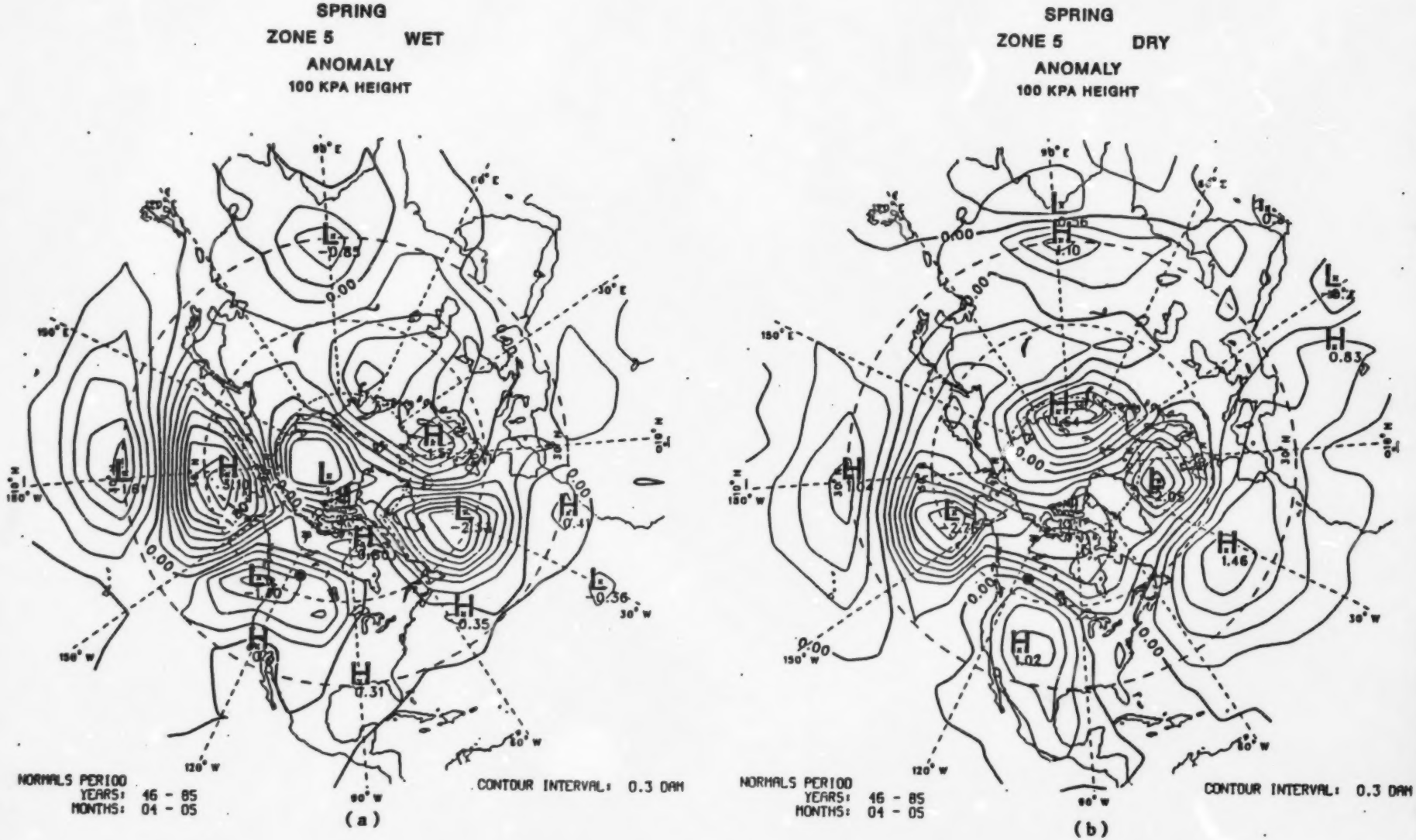

FIGURE B.3. 100kPa Height anomaly chart for Spring, Zone 5 for:
a.) wet and
b.) dry months.

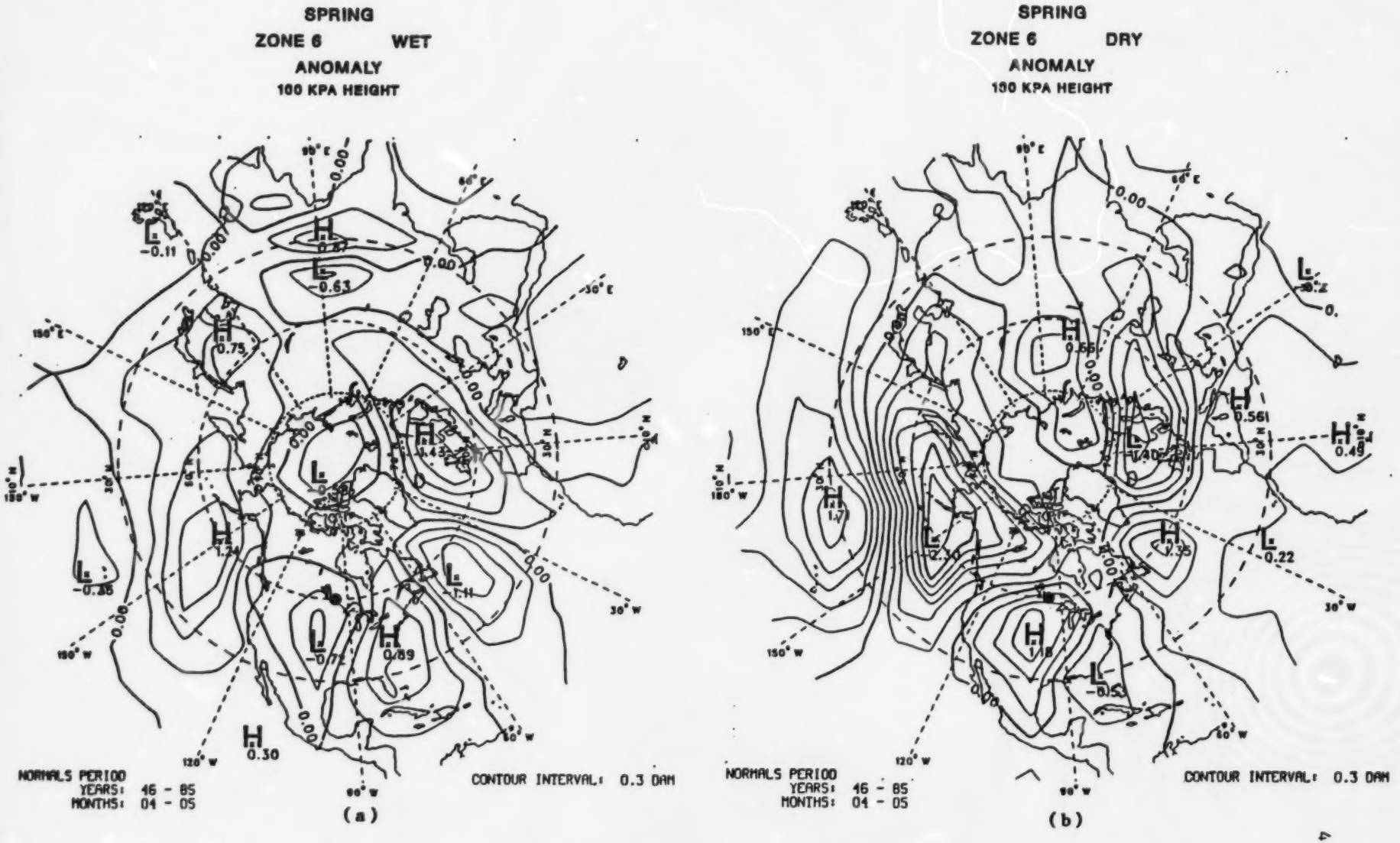

FIGURE B.4. 100kPa Height anomaly chart for Spring, Zone 6 for:
a.) wet and
b.) dry months.

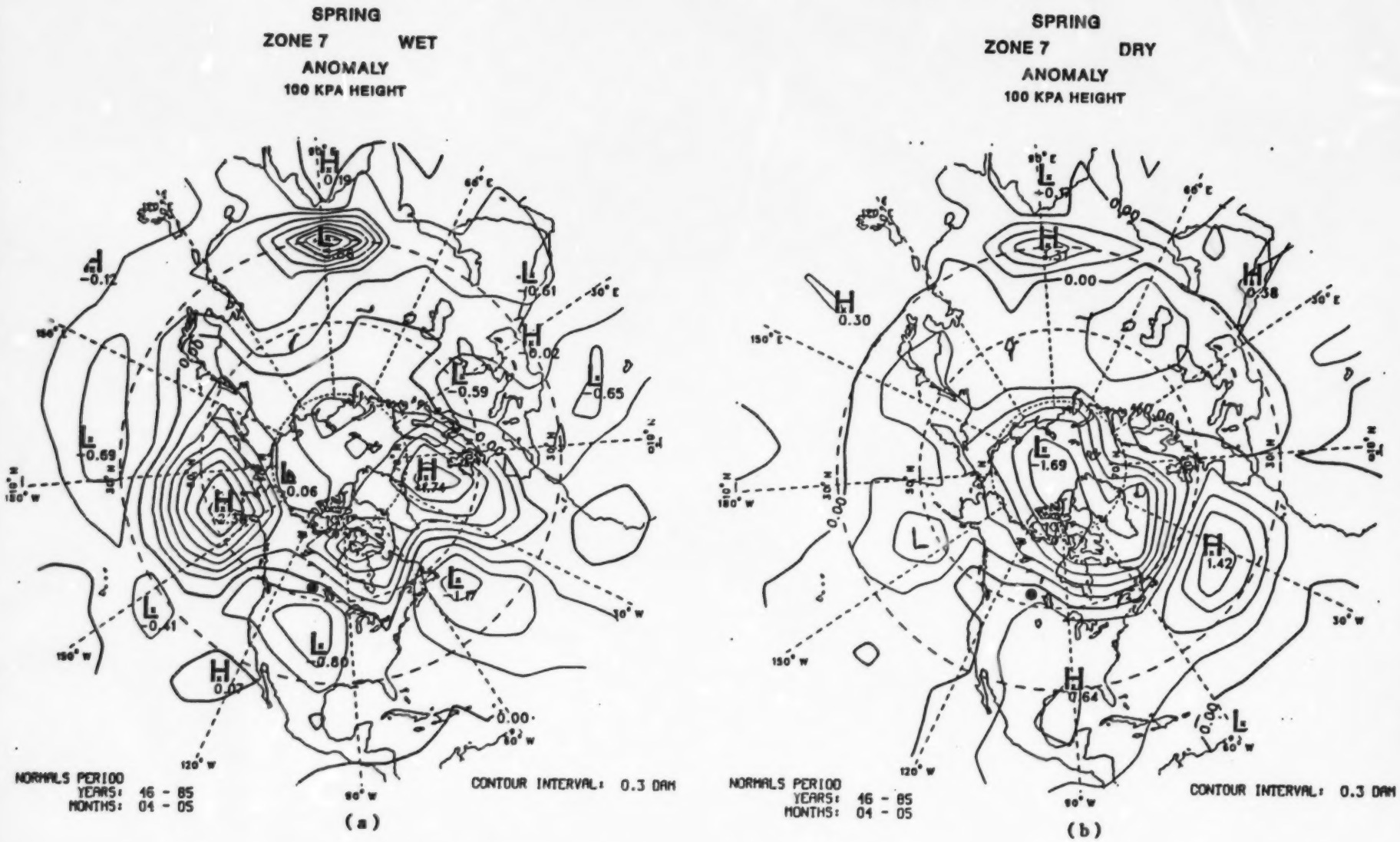

FIGURE B.5. 100kPa Height anomaly chart for Spring, Zone 7 for:
a.) wet and
b.) dry months.

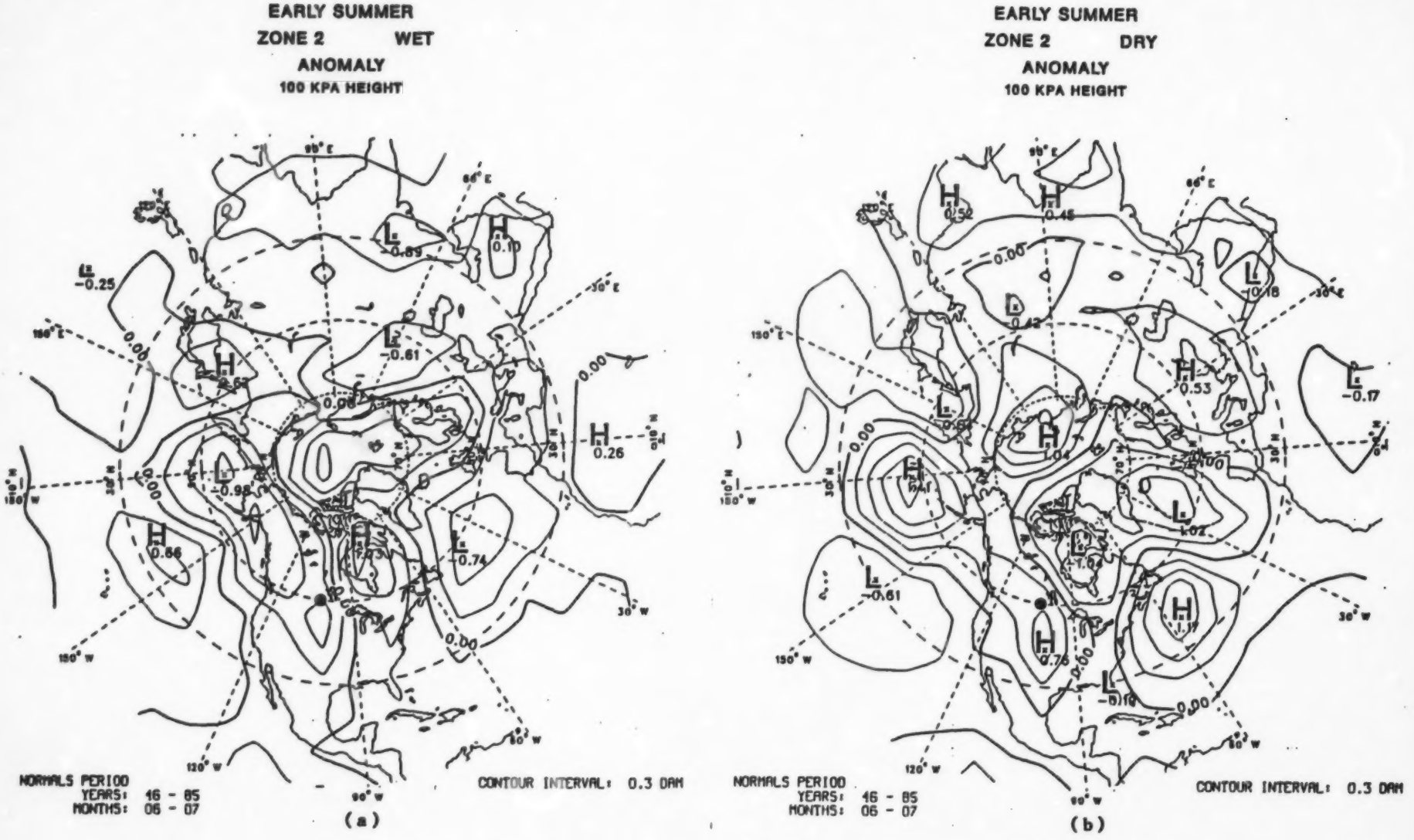

FIGURE B.6. 100kPa Height anomaly chart for Early Summer, Zone 2 for:

a.) wet and
b.) dry months.

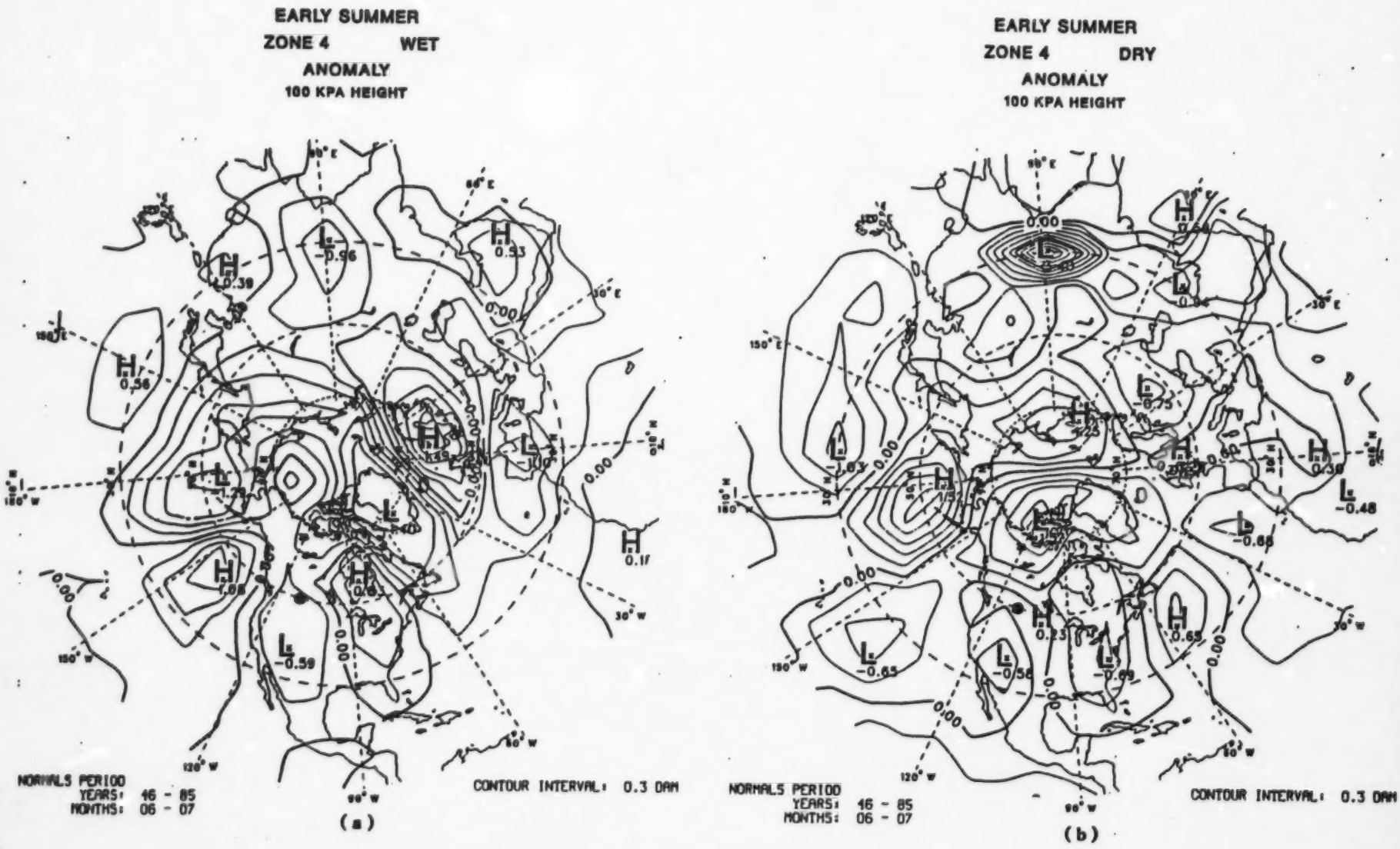

FIGURE B.7. 100kPa Height anomaly chart for Early Summer, Zone 4 for:

a.) wet and
b.) dry months.

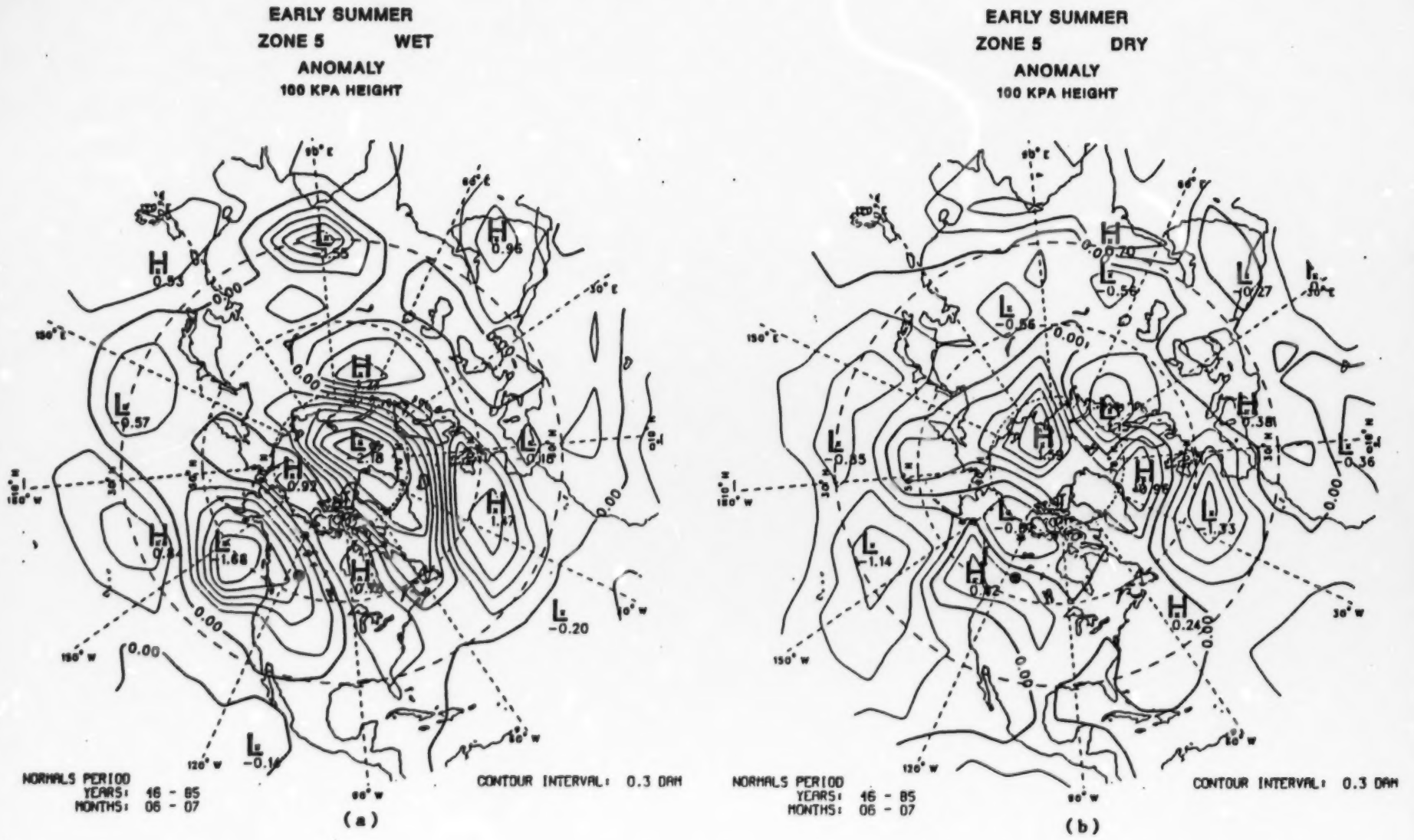

FIGURE B.8. 100kPa Height anomaly chart for Early Summer, Zone 5 for:

a.) wet and
b.) dry months.

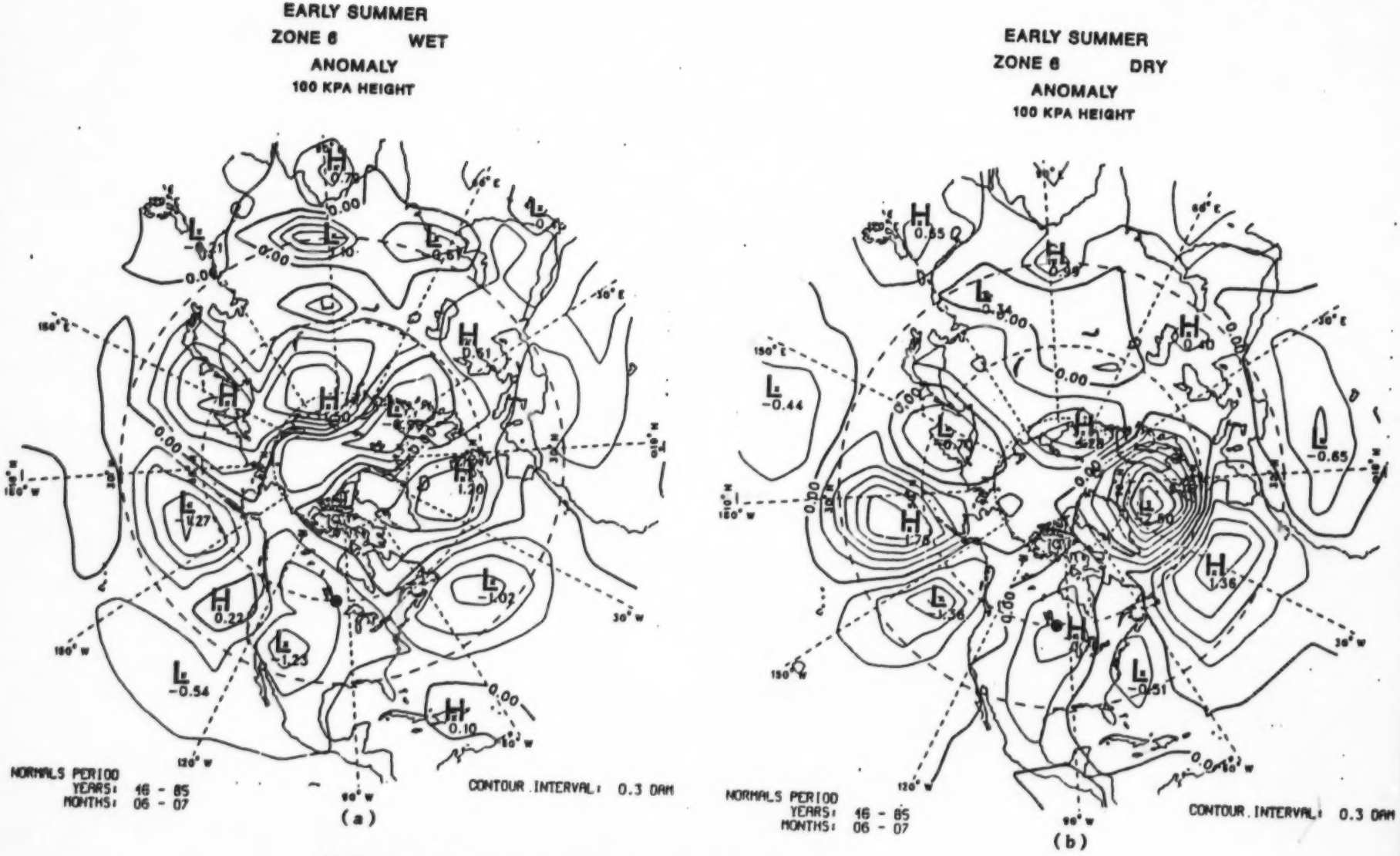

FIGURE B.9. 100kPa Height anomaly chart for Early Summer, Zone 6 for:

a.) wet and
b.) dry months.

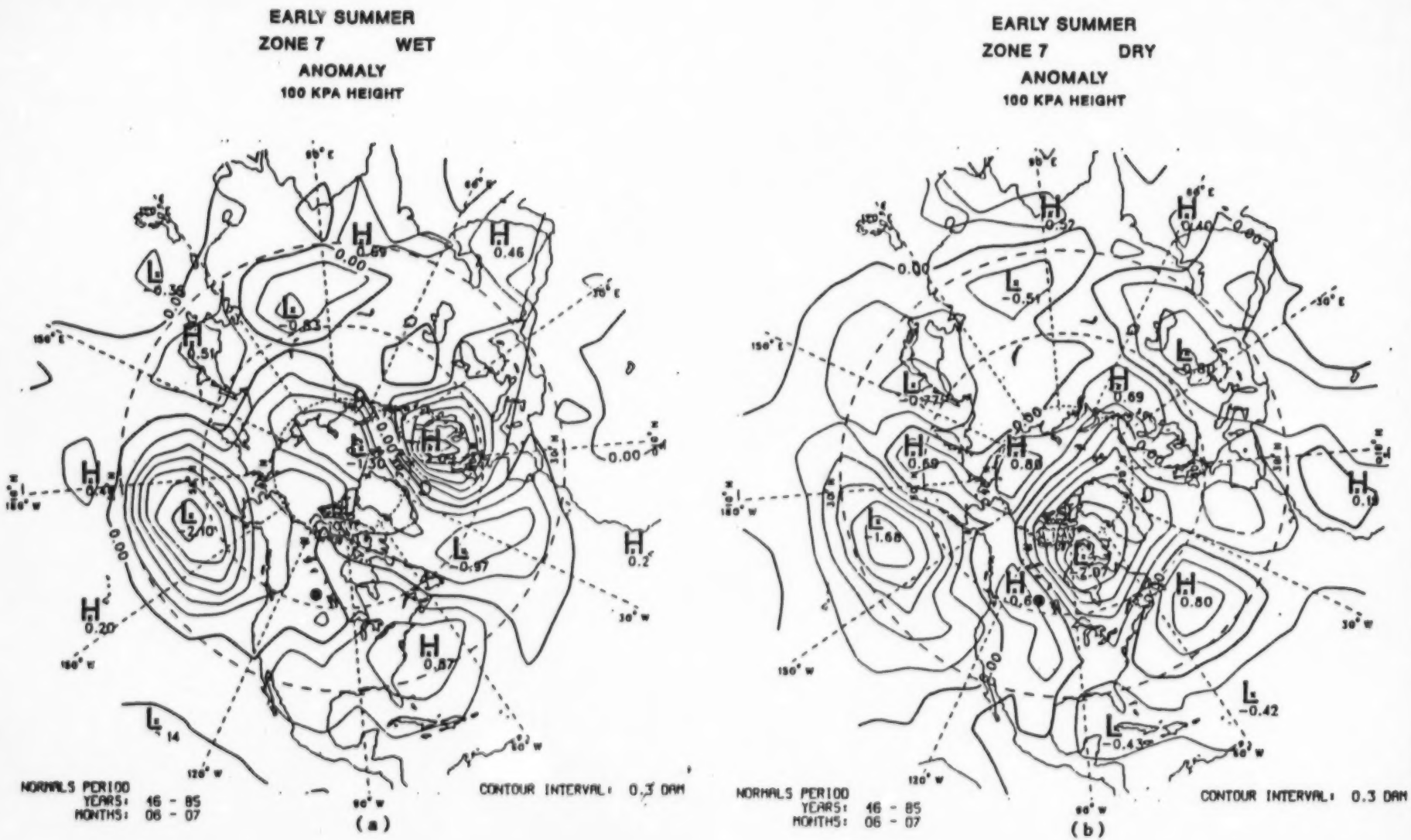

FIGURE B.10. 100kPa Height anomaly chart for Early Summer, Zone 7 for:

a.) wet and
b.) dry.months.